STIMULUS EQUIVALENCE AND ARBITRARILY APPLICABLE RELATIONAL RESPONDING

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Subjects' responses to nonarbitrary stimulus relations of sameness, oppositeness, or difference were brought under contextual control. In the presence of the SAME context, selecting the same comparison as the sample was reinforced. In the presence of the OPPOSITE context, selecting a comparison as far from the sample as possible on the physical dimension defined by the set of comparisons was reinforced. Given the DIFFERENT context, selecting any comparison other than the sample was reinforced. Subjects were then exposed to arbitrary matching-to-sample training in the presence of these same contextual cues. Some subjects received training using the SAME and OPPOSITE contexts, others received SAME and DIFFERENT, and others received SAME, OPPOSITE, and DIFFERENT. The stimulus networks established allowed testing for a wide variety of derived relations. In two experiments it was shown that derived performances were consistent with relational responding brought to bear by the contextual cues. In contexts relevant to the relation of sameness, stimulus equivalence emerged. Other kinds of relational networks emerged in the other contexts. Arbitrarily applicable relational responding may give rise to a very wide variety of derived stimulus relations. The kinds of performances seen in stimulus equivalence do not appear to be unique.

Key words: stimulus equivalence, relational responding, relational frames, nonarbitrary stimulus relations, arbitrary stimulus relations, stimulus control, matching to sample, button press, humans

The basic phenomenon now called stimulus equivalence has had several incarnations in modern psychology. In 1971 Sidman resurrected the area by linking it to a powerful procedure: matching to sample. Since then, behavior-analytic research has focused on the limits of the equivalence phenomenon (e.g., populations, stimulus modality, stimulus arrangements), refinement of its measurement (e.g., Sidman & Tailby, 1982), and descriptions of conditions under which it may arise (e.g., Sidman, 1986). Behavior analysts have devoted little attention, however, to a theoretical account of equivalence. At present, stimulus equivalence is merely the description of a behavioral outcome—the process involved is unknown.

Early researchers (e.g., Sidman & Cresson, 1973; Spradlin, Cotter, & Baxley, 1973) tentatively discussed their work in terms of possible response mediation, much along the lines of stimulus-response learning theory. Response mediation was later rejected as unnec-

essary on the grounds that the particular responses (i.e., selecting stimuli) are only differentiated with reference to the stimuli involved and thus add little to the explanation of the derived stimulus relations themselves (Sidman, 1986; Sidman, Cresson, & Willson-Morris, 1974; Sidman & Tailby, 1982). Recently, response mediation models have reemerged in the form of naming-based interpretations (e.g., McIntire, Cleary, & Thompson, 1987). The effects of naming, however, also require a theoretical explanation. The proposed alternatives either do not yet have experimental support, as in McIntire et al.'s homogeneous chain model (Hayes, 1989; K. Saunders, 1989), or themselves assume name-object derived relations in order to explain similar derived relations between samples and comparisons.

A recent account views equivalence as the result of relational responding arbitrarily applied to the matching-to-sample situation (Hayes, 1991; Hayes & Hayes, 1989). Organisms from insects to primates can learn to respond to nonarbitrary relations among stimuli (e.g., larger than, darker than; see Reese, 1968). These relations can be brought under contextual control and can generalize to new

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sets of formally related stimuli (Lowenkron, 1989). Verbal humans, however, seem also to apply these kinds of relations when there are contextual cues to do so without significant regard for the form of the items being related. The reader told that A = B > C will be able to specify the relation between A and C (>) or C and A (<) and so on, but the letters A, B, and C had nothing to do with the particular relations being applied. Such arbitrarily applicable relations have been termed "relational frames" (Hayes & Hayes, 1989). Relational frame theory holds that arbitrarily applicable relational responding has an extensive history, largely in the context of language training, that can be brought into the experimental situation by virtue of contextual cues to do so. In this view, stimulus equivalence as commonly seen may be the result of an application of a learned frame of "coordination" (sameness) to the stimuli in arbitrary matching-to-sample procedures.

A wide variety of relational frames are possible, and the nature of the derived performances they comprise varies widely. For example, the abstract relation of oppositeness has the property that an opposite of an opposite is the same, an opposite of an opposite of an opposite is an opposite, and so on. Whereas stimulus equivalence may be an outcome of a history establishing the frame of sameness or coordination, frames of opposition or of distinction would give rise to very different kinds of relational networks. Conditional discrimination training could thus give rise to no derived performances, derived equivalence, or other derived relations, depending on the nature of the relations brought to bear on these discriminations via the contextual cues involved.

The relational frame concept requires a distinct nomenclature, part of which will be reviewed because it is necessary to a description of the present experiments and their results. Symmetry, although appropriate for equivalence, is not an appropriate general term for all arbitrarily applicable relations because many are not strictly symmetrical (Russell, 1919, 1937). For example, if A is better than B, then B is worse than A. Hayes (1991; Hayes & Hayes, 1989) suggested the term *mutual entailment,* defined as follows:

$$Crel_x\{A\ rel_xB\ |||\ B\ rel_yA\}.$$

That is, in a context that brings a particular kind of relational responding to bear ($Crel_x$), the designation of that relation between Events A and B through direct training entails (entailment is symbolized by $|||$) a derived relation between B and A (rel_y) that may or may not be the same as the designated relation. In these terms, symmetry is a special case of mutual entailment.

Similarly, transitivity is not applicable to all kinds of arbitrarily applicable relational responding (Russell, 1919, 1937). Hayes and Hayes (1989) suggested the term *combinatorial entailment,* defined as follows:

$$Crel_x\ and\ Crel_y\{A\ rel_xB\ and\ B\ rel_yC\ |||\ A$$
$$\cdot rel_pC\ and\ C\ rel_qA\}.$$

That is, given contexts ($Crel_x$ and $Crel_y$) that specify mutual relations (rel_x and rel_y) among three or more items, relations are entailed (rel_p and rel_q) between the stimuli based on the combinations of these mutual relations. In these terms, transitivity and the equivalence relation described by Fields, Verhave, and Fath (1984) are special cases of combinatorial entailment.

Reflexivity, in Sidman's sense, can always involve recognizing stimuli as themselves based upon formal properties of the stimuli involved. Identity matching based on form is, by definition, not an arbitrary relation. Relations in the abstract, however, can either be reflexive or irreflexive. For example, the arbitrary relation of sameness is reflexive, but oppositeness is not (A cannot be the opposite of A). We will use the term *relational reflexivity/irreflexivity* to refer to the relation of a stimulus to itself in a given relational context. This is viewed as a special case of mutual entailment.

The present study sought to establish three different types of relational responding (same, different, and opposite) and apply them to an arbitrary matching-to-sample context. Derived performances were then examined to see if they could be understood as instances of mutual and combinatorial entailment.

EXPERIMENT 1

The strategy in this experiment was to pretrain arbitrary contextual cues to control same, opposite, or different responding with nonarbitrary stimulus sets. Four subjects were exposed to same and opposite pretraining, and 3 were exposed to same and different pretrain-

ing. These pretrained cues were then used in an arbitrary matching-to-sample context, and the impact of the cues on derived stimulus relations was examined. Two control subjects were given arbitrary matching-to-sample training, but without pretraining with regard to the contextual cues. Relations among the training stimuli were assessed in unreinforced testing trials given to both the experimental and control subjects.

The network of relations presented diagrammatically in Figure 1 allowed the assessment of a variety of derived relations. Consider, for example, the relation "opposite." If A1 is the opposite of B2 and A1 is the opposite of C2, B2 and C2 are the same, not opposite. Thus, we wanted to assess whether subjects trained to pick B2 and C2 (given A1) only in the presence of a pretrained cue for an "opposite" relation would now *not* pick B2 given C2 in the presence of that cue, but instead would do so in the presence of a pretrained cue for a "same" relation. Similarly, stimuli related across three stages of the opposite relation are opposites: If A1 is the opposite of B2, A1 is the opposite of C2, and C2 is the opposite of D1, then B2 and D1 are opposites. Thus, we assessed whether subjects trained to pick these stimuli in the presence of a pretrained cue for an "opposite" relation would now pick B2 given D1 in the presence of that cue, but *not* in the presence of pretrained cue for a "same" relation.

METHOD

Subjects

Nine subjects, 13 to 17 years old, were recruited through offers of paid participation. Five were male, and 4 were female. Subjects were paid at a mutually agreed upon rate based on their usual rate of compensation for part-time work such as baby-sitting, but received no less than $2.00 per hour. All subjects were in college preparatory classes in high school.

Procedure

Sessions lasted up to 2 hr and were generally scheduled on consecutive days for individual subjects. The following instructions were given at the start of the first session:

This is an experiment in learning. It is not a psychological test of any kind. We are inter-

Trained Relations
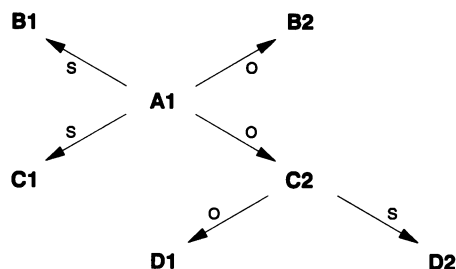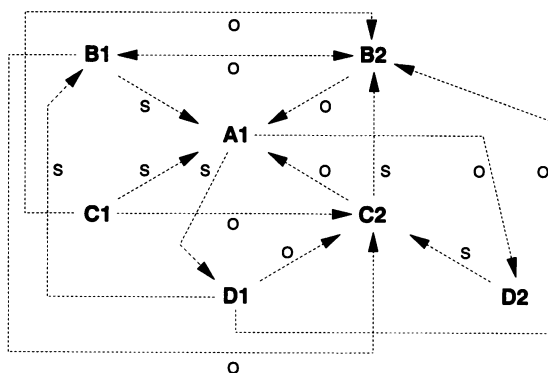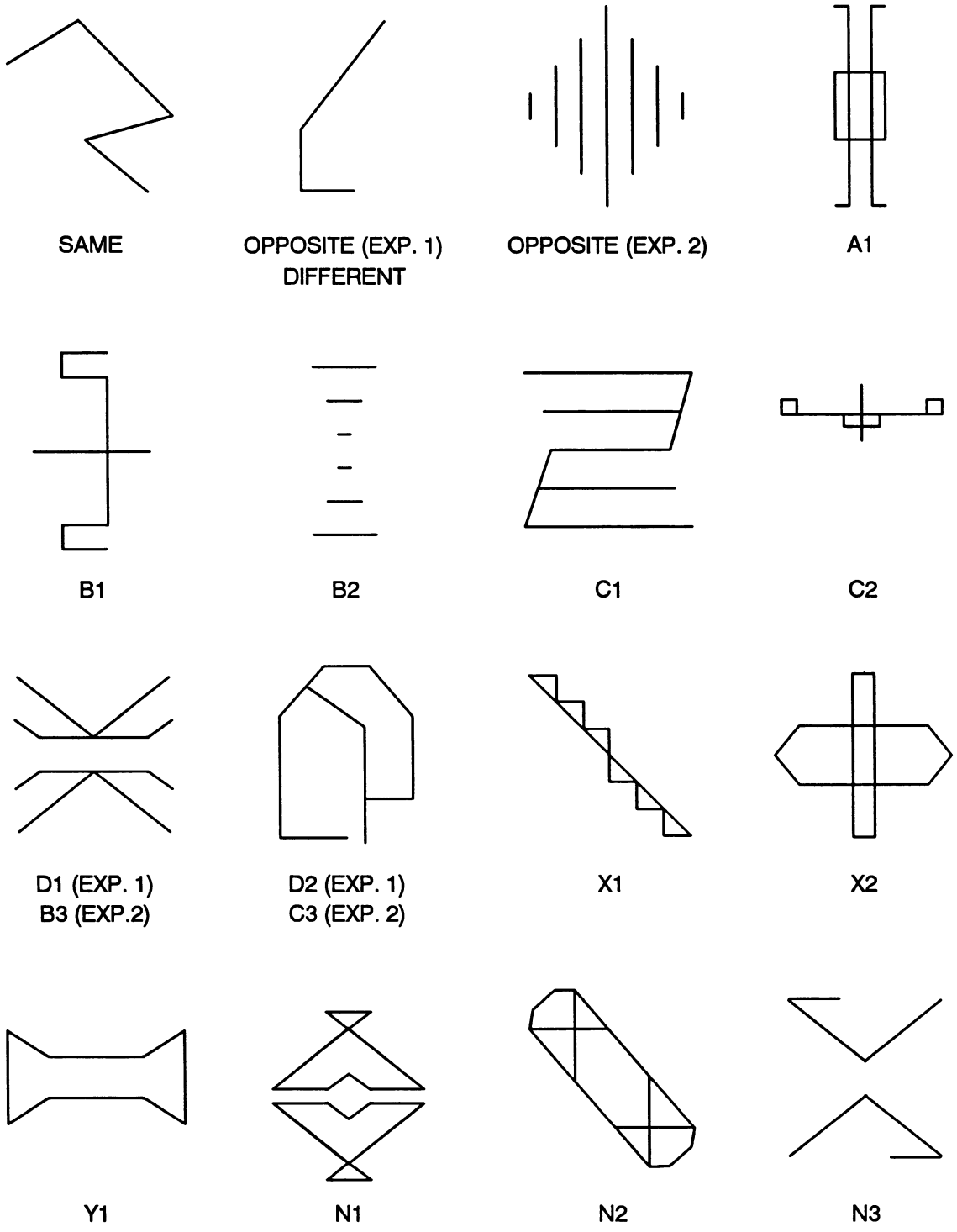

Basic Set of Tested Derived Relations

Fig. 1. Basic network of relations trained and tested in Experiment 1. Solid arrows indicate trained discriminations, and dashed arrows indicate assessment of relations by probe items. Letters S or O indicate relational stimulus SAME or OPPOSITE. Same/different subjects were trained in the same fashion but DIFFERENT was used in place of OPPOSITE. Additional relations were trained and tested with some subjects (see tables and figures).

ested in aspects of learning common to all people.

When the experiment begins, the screen in front of you will show some geometric figures. There will be either two or three figures at the bottom of the screen. Your task is to choose one of these figures by using the joystick. The joystick controls the movement of a box on the screen. Move the joystick until the box is around the figure you want to choose. Then press the button on the joystick. Sometimes there will be two figures in the bottom section of the screen, and at other times there will be three. You make your choice the same way in either case.

Sometimes, after you press the button, a message on the screen will tell you whether or not you have made the correct choice. We want you to learn to make as many correct responses as possible. Try to make correct responses on all problems. At first, the problems may be easy, but they will get harder. You will need to pay

Stimuli Used in Experiments

SAME	OPPOSITE (EXP. 1) DIFFERENT	OPPOSITE (EXP. 2)	A1
B1	B2	C1	C2
D1 (EXP. 1) B3 (EXP.2)	D2 (EXP. 1) C3 (EXP. 2)	X1	X2
Y1	N1	N2	N3

(stimuli randomly reassigned for Subject 4. See text.)

Fig. 2.   Arbitrary visual stimuli used in training and probe items in Experiments 1 and 2.

attention right from the start, because what you learn at first can be used later to make correct responses.

If you have any questions, ask them now. I cannot answer any questions after you start.

Subjects were seated at a table in front of a computer monitor connected to a Radio Shack® Color Computer and a joystick. All experimental tasks were presented and monitored via the computer (software, written in CoCoBASIC, is available from the first author). In a given trial, an arbitrary visual stimulus cueing the relation involved was presented in the center of the top third of the monitor screen. (By convention, we will refer to these second-order conditional stimuli by the generic name of "relational" stimuli; when speaking of a specific type we will refer to them as the SAME, OPPOSITE, or DIFFERENT stimuli, capitalized to avoid literal confusion.) After 2 s, the sample stimulus was presented in the center of the middle third of the screen. After another 2 s, the comparison stimuli were presented in random positions (left, center, or right) at the bottom of the screen while the relational and sample stimuli remained. All stimuli used in the experiment are shown in Figure 2.

Moving the lever on the joystick from left to right moved a box on the monitor screen so as to surround one of the available comparison stimuli. Pressing a button on the joystick case "selected" the stimulus inside the box. In addition to recording the comparison selected, for each trial latency of response was recorded from the complete presentation of the comparisons to a selection response. No special instructions regarding speed of responding were given to the subjects (see instructions above). During training and reviews of previously trained relations, feedback was given. When the response was correct, two tones sounded and "correct" appeared on the screen. If a response was incorrect, a repetitive low-pitched tone sounded and "wrong" appeared.

Pretraining for same/opposite control. Four subjects were given same/opposite pretraining. During pretraining, it was possible to relate the sample and comparison stimuli on the basis of their physical properties. Eight sets of stimuli were used, each with three comparison stimuli varying on a single physical dimension: (a) short to long lines; (b) small to large squares; (c) sets of few to many dots; (d) sets of closely spaced to distantly spaced lines; (e) a scale with a cursor that is located at the top, bottom, or

middle; (f) a scale with a cursor that is located at the left, right, or center; (g) figures drawn with very thick to thin lines; and (h) tall to short lines. Each set was presented with the sample drawn from either end of the range of differences, yielding 16 different sets of sample and comparison stimuli. For example, a short line might appear as the sample and short, medium, and long lines might appear as comparisons. In the presence of the SAME stimulus, selection of the short line was reinforced. In the presence of the OPPOSITE stimulus, the selection of the longest line was reinforced.

Training was conducted in blocks of 20 trials. Within each block, the number of trials with the sample drawn from a given end of the continuum or using a given relational stimulus was balanced. For example, when comparisons were long to short lines, the OPPOSITE stimulus was presented for 10 trials, five trials with the short line as sample and five trials with the long line as sample. A similar procedure was used for the SAME stimulus, yielding a total of four specific problems in each set. Individual trials within a block were intermixed in random order.

Subject 2 did not respond correctly to pretraining problems presented concurrently, so the procedure was modified slightly for this subject. A given problem was presented over and over until 90% accuracy was achieved in a 20-trial block, and then a different problem was presented. After accurate responding was established to each of the four problems in a set (presented serially), all four problems in the set were presented in mixed blocks. After the initial three stimulus sets were learned using this procedure, Subject 2 was able to master the remaining pretraining tasks with the general procedure used with all other subjects.

The first part of pretraining with feedback was conducted with three sets of stimuli—long to short lines, large to small squares, and tall to short lines. The subjects had to achieve a 90% accuracy rate on each set of stimuli before going on to the next set. Once responding on all three sets was at the 90% accuracy level, problems from the three sets were presented concurrently in blocks of 32 trials. When a 90% accuracy rate within a block was achieved, unreinforced probes were used to test for generalized control by the relational stimuli: A novel set of stimuli (from the eight above) was presented for six trials with no feedback (three

trials with each kind of relational stimulus). If any errors were made in relational responding to the novel stimuli, responses to this set of stimuli were trained to criterion and another set of novel stimuli was presented for six trials. If all responses to a novel set of stimuli were correct, additional novel sets were presented without feedback. The criterion for successful pretraining was errorless performance on all trials during the presentation of three consecutive novel sets of stimuli. If a subject made any incorrect responses with a set of stimuli, responses to those stimuli were trained with feedback and an additional set of novel stimuli was presented.

Pretraining for same/different control. Three subjects received same/different pretraining. This was identical to the same/opposite training above except that the DIFFERENT relational stimulus was used instead of OPPOSITE and only two comparisons were presented, one of which was identical to the sample. There was no particular physical dimension along which the two comparisons differed (e.g., the two comparisons might be a rectangle and a circle). In the presence of the SAME stimulus, the selection of the comparison that was identical to the sample was reinforced. In the presence of the DIFFERENT stimulus, selection of the comparison that was not identical to the sample was reinforced. Two comparisons were used with these subjects because if three comparisons were used, there would be two correct answers in the presence of the DIFFERENT stimulus. This could have distracted the subjects from the specific nature of the relation being trained. Training was conducted in blocks of 20 trials—10 trials with the SAME stimulus and 10 with the DIFFERENT stimulus. Each block used one set of two arbitrary stimuli (e.g., a rectangle and a circle), and each stimulus in the set was used as the sample an equal number of times.

Arbitrary matching-to-sample training. In the tables and in the text for all experiments, arbitrary matching-to-sample problems and probes are described using the same conventions. The relational stimulus is given first, using the letters S, O, and D to represent the SAME, OPPOSITE, and DIFFERENT stimuli. The next letter/number combination in brackets is the sample, and the next set of number/letter combinations separated by dashes is the set of comparison stimuli. The

reinforced comparison, or the "correct" one in probe trials, is italicized. For example, the notation O[A1]B1-B2-*B3* indicates that in the presence of the OPPOSITE stimulus, selecting B3 given A1 was reinforced or correct. At times there is no need to describe the unreinforced (or "incorrect") comparisons and only the reinforced or predicted comparison is given.

All subjects received arbitrary matching-to-sample training: 4 with SAME and OPPOSITE relational stimuli, 3 with SAME and DIFFERENT (using the network of relations shown in Figure 1 except that some subjects had DIFFERENT instead of OPPOSITE), and 2 control subjects who received no pretraining but were otherwise treated identically to the same/opposite subjects. In all training blocks each problem was presented for 10 trials, randomly intermixed with the other problems. The size of the training block thus depended on the number of specific problems involved.

The basic training and testing sequences are presented diagrammatically in Figure 3. Examination of Figure 3 is essential to an understanding of this complex experiment. The basic flow of events was as follows. First, A-B and Y-X relations were trained. Y-X trials were included so that the X stimuli would provide a pool of incorrect comparisons that have a history of reinforced selection and could be used in subsequent probes for mutual entailment and combinatorial entailment. Probes then assessed whether the subjects showed mutual entailment (e.g., S[B1]*A1*-X2) and relational reflexivity/irreflexivity (e.g., O[A1]A1-N2). Note that a novel stimulus, N2, was used in this test to avoid complicating the relational network. Then combinatorial entailment (e.g., O[B1]*B2*-X1) of the trained relations was assessed. Following each additional training set (A-C and C-D relations) all of the trained relations were reviewed concurrently with feedback given on each trial, and probes assessed mutual entailment and combinatorial entailment of the trained relations without feedback. To advance to the next phase of the study, a subject had to achieve 90% accuracy for the block of trials and no lower than 80% accuracy on any given problem. Failure to achieve criterion resulted in a return to the same training block.

The number of different types of training and testing trials was kept to the minimum
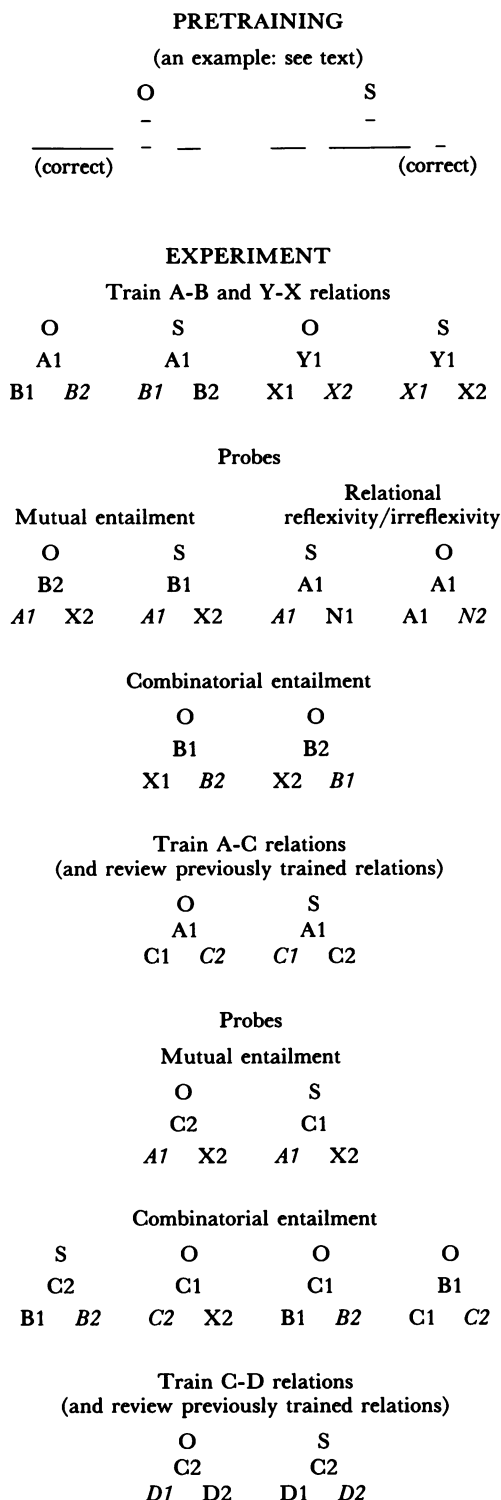
PRETRAINING

(an example: see text)

O   S
-                     -
_____ - __   ___ _____ -
(correct)   (correct)

EXPERIMENT

Train A-B and Y-X relations

O   S   O   S
A1   A1   Y1   Y1
B1   *B2* *B1* B2   X1   *X2*   *X1* X2

Probes

| | Relational |
| Mutual entailment | reflexivity/irreflexivity |

O   S   S   O
B2   B1   A1   A1
A1 X2   *A1* X2   *A1* N1   A1   *N2*

Combinatorial entailment

O   O
B1   B2
X1   *B2*   X2   *B1*

Train A-C relations
(and review previously trained relations)

O   S
A1   A1
C1   *C2* *C1* C2

Probes

Mutual entailment

O   S
C2   C1
A1 X2   *A1* X2

Combinatorial entailment

S   O   O   O
C2   C1   C1   B1
B1 *B2*   *C2* X2   B1 *B2* C1 *C2*

Train C-D relations
(and review previously trained relations)

O   S
C2   C2
D1 D2   D1 *D2*

Fig. 3. The basic training and testing sequence for Experiment 1. Specific sequences varied for some subjects.

Probes

Mutual entailment

O   S
D1   D2
C1   *C2* C1   *C2*

Combinatorial entailment

O   S   O   S
D1   D1   A1   A1
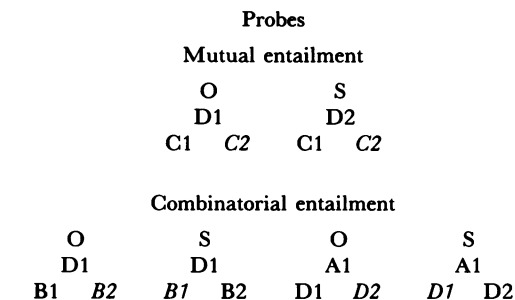B1 *B2*   *B1* B2   D1 *D2*   *D1* D2

Fig. 3. (*Continued*)

needed to support or disconfirm the presence of a derived relational network. A network based on a lean set of examples was experimentally advantageous in part because the task was quite complex and we did not wish to overload the subjects. The primary concern, however, was that derived relations can emerge in increasingly complex and difficult-to-predict ways (e.g., through combinations of exclusion and equivalence) in complex relational networks of the kind trained in this experiment. The results from uncluttered networks are thus more open to the detection of sources of control other than those intended. In the training and testing sequence as described, it may not be immediately obvious why specific problems were constituted as they were (e.g., why certain comparison stimuli were used), or why only a certain subset of tests was done, or why tests were conducted in particular sequences. The number of considerations involved were very numerous and thus explanations for every decision are not included in this report, but the driving consideration was the development of a network in which the sources of control over responding went beyond equivalence and simple forms of exclusion, or other sources such as reinforcement density or consistent reinforced pairings between relational stimuli and specific comparisons. For example, in Experiment 1 testing for combinatorial entailment dealing solely with same (B1-C1) was delayed or avoided entirely to reduce the chance that performances derived through relations of different or opposite involved simple exclusion via a previously established equivalence relation.

Testing blocks. Two to four types of probes were presented in the testing trial blocks, randomly alternating with previously trained
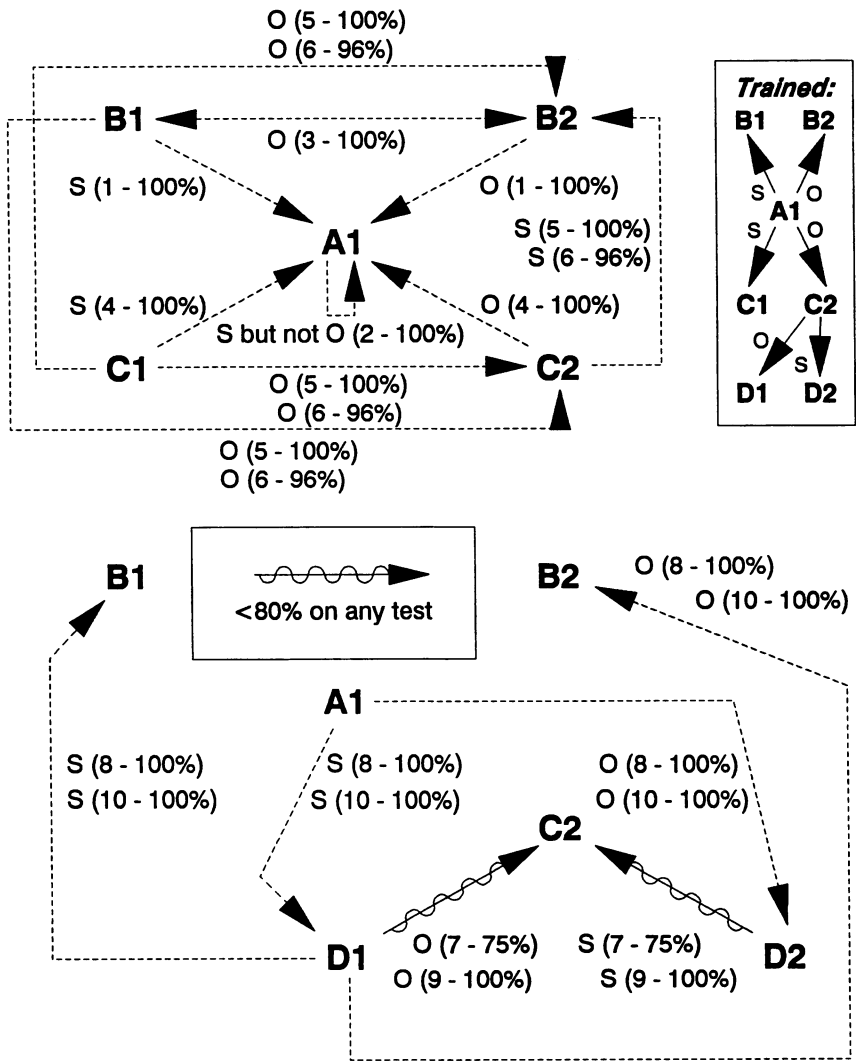
Subject 1 (Pretrained Same/Opposite)

Fig. 4.   Testing performance of Subject 1 (pretrained with SAME and OPPOSITE). Dashed lines indicate probes that were above 80% correct, where "correct" is defined as selecting the indicated stimulus. Wavy lines indicate probes were below 80% on at least one of the testing blocks recorded in that section. The letters S and O indicate the relational stimulus presented. Numbers in parentheses indicate the specific testing block (these same numbers are used in Table 1 for cross reference) and the percentage correct. See Table 1 for specific comparison stimuli used and training sequences.

problems, all without feedback. In any given block, all types of probes were presented an equal number of times (a minimum of eight), and the total number of probe trials and the number of trials over previously trained problems were equal. These constraints dictated the total number of trials in a given block. For example, if a block was to contain six previ- ously trained problems presented without feedback and four types of probes, each type of probe would be presented on nine trials (for a total of 36 probe trials) and each trained problem would be presented without feedback on six trials (for a total of 36 trials). Each block of trials was planned for the smallest number of trials that would meet these criteria.

Table 1

Percentage of correct responses on training problems and probes for Subject 1 (SAME/OP-POSITE pretrained).

Trained problem or testing probe	% Correct
Train A-B and Y-X relations (total of 40 trials)	93
1. Probe B-A mutual entailment: O[B2]*A1*-X2 and S[B1]*A1*-X2	100
2. Probe relational reflexivity/irreflexivity	100
3. Probe combinatorial entailment: O[B1]*B2*-X1 and O[B2]*B1*-X2	100
Train A-C relations (total of 20 trials)	95
Review A-C, A-B, and Y-X with feedback (24 trials)	100
4. Probe C-A mutual entailment: O[C2]*A1*-X2 and S[C1]*A1*-X2	100
5. Probe combinatorial entailment: S[C2]B1-*B2*, O[C1]*C2*-X2, O[C1]B1-*B2*, and O[B1]C1-*C2*	100
[Break between sessions]	
Review A-B, A-C, and Y-X with feedback (24 trials)	100
6. Probe combinatorial entailment: S[C2]B1-*B2*, O[C1]*C2*-X2, O[C1]B1-*B2*, and O[B1]C1-*C2*	96
Train C-D relations (20 trials)	100
Review A-B, Y-X, A-C, and C-D with feedback (32 trials)	98
7. Probe D-C mutual entailment: O[D1]C1-*C2* and S[D2]C1-*C2*	75
8. Probe combinatorial entailment: O[D1]B1-*B2*, S[D1]*B1*-B2, O[A1]D1-*D2*, and S[A1]*D1*-D2	100
Review C-D relations (5 trials each, 10 trials total)	100
9. Probe D-C mutual entailment: O[D1]C1-*C2* and S[D2]C1-*C2*	100
10. Probe combinatorial entailment: O[D1]B1-*B2*, S[D1]*B1*-B2, O[A1]D1-*D2*, and S[A1]*D1*-D2	100

The criterion for mastery was 90% accuracy for the block of probes and no lower than 80% accuracy on any given type of probe. Usually, when a subject failed to achieve these accuracy rates, he or she was given a review of all previously trained problems; this was followed by a return to the same block of probes where the difficulty was encountered. Because repeated reviews might provide the subject with feedback about inaccuracy, if three reviews did not produce accurate responding on a given probe block, other problems were presented before returning to the problematic set of probes.

Use of expanded probe sets. Sometimes a subject failed to show correct responding even after reviewing trained relations. Because we had chosen to use an abbreviated set of all possible probes, it then was possible to give subjects additional related probes without providing any feedback about current or previous responses. Several studies have shown that testing of relations alters the emergence of other relations (e.g., Harrison & Green, 1990; Kennedy & Laitinen, 1988). The use of expanded probe sets contributed to the complexity of the resulting designs for individual subjects. A thorough description of the exact training and testing sequences actually used in a given case is more easily understood in the context of the Results section and is presented there.

RESULTS

Subjects Who Received Same/Opposite Pretraining

Pretraining. Pretraining was accomplished in the following number of training blocks: Subject 1, eight 20-trial blocks; Subject 2, 15 blocks; Subject 3, eight blocks; and Subject 4, eight blocks. Subject 2 was the only subject to experience substantial difficulty with the pretraining process. A special procedure (described previously) was used in the initial part of the pretraining with Subject 2.

Matching-to-sample training. All of the subjects who received same/opposite pretraining achieved a 90% accuracy rate for A-B relations in the first block of 40 training trials. They also were better than 90% accurate in the first 20-trial block of A-C training. Subjects 1, 3, and 4 achieved accuracy rates of at least 90% in the first 20-trial block of C-D training. (Subject 2 chose to withdraw prior to this phase.)

Responses to probes. Testing results for derived relations shown by Subject 1 are pictured in Figure 4. Table 1 shows more complete information on retraining and testing sequences and the specific comparisons used. Subject 1 responded correctly on 96% to 100% of all probes following A-B and A-C training.

Subject 2 (Pretrained Same/Opposite)

B1

B2
O (1 - 40%)
O (2 - 100%)
O (3 - 100%)
O (4 - 100%)
O (5 - 100%)

A1

S (1 - 60%)
S (2 - 0%)
S (3 - 0%)
S (4 - 0%)
S (5 - 0%)
S (6 - 100%) -
New comparisons

Trained:
B1   B2
S   O
A1
S   O
C1   C2

<80% on any test

O (13 - 0%)
O (14 - 0%)

B1   **B2**

O (8 - 95%)

S (10 - 0%)
S (12 - 100%)

S (9 - 100%)   **A1**
S (11 - 100%)   O (9 - 100%)
S but not O (7 - 100%)

C1   **C2**
O (10 - 100%)
O (12 - 100%)

O (13 - 0%)
O (14 - 0%)

S (11 - 100%)

O (17 - 100%)

B1   **B2**

S (16 - 100%)   S (16 - 100%)

A1
O (15 - 100%)
S (15 - 100%)

C1   **C2**
O (17 - 100%)

O (17 - 100%)   S (16 - 100%)

Fig. 5.   Testing performance of Subject 2 (pretrained with SAME and OPPOSITE). Dashed lines indicate probes that were above 80% correct, where "correct" is defined as selecting the indicated stimulus. Wavy lines indicate probes were below 80% on at least one of the testing blocks recorded in that section. The letters S and O indicate the relational stimulus presented. Numbers in parentheses indicate the specific testing block (these same numbers are used in Table 2 for cross reference) and the percentage correct. See Table 2 for specific comparison stimuli used and training sequences.

Table 2

Percentage of correct responses on training problems and probes for Subject 2 (SAME/OP-POSITE pretrained).

Trained problem or testing probe	% Correct
Train A-B and Y-X relations (40 trials)	100
1. Probe B-A mutual entailment: O[B2]*A1*-X2	40
and S[B1]*A1*-X2	60
Review A-B and Y-X with feedback (total of 40 trials)	96
2. Probe B-A mutual entailment: O[B2]*A1*-X2	100
and S[B1]*A1*-X2	0
Review A-B and Y-X with feedback (40 trials)	100
3. Probe B-A mutual entailment: O[B2]*A1*-X2	100
and S[B1]*A1*-X2	0
4. Probe B-A mutual entailment: O[B2]*A1*-X2	100
and S[B1]*A1*-X2	0
[Break between sessions]	
Train A-B and Y-X relations (40 trials)	93
5. Probe B-A mutual entailment: O[B2]*A1*-X2	100
and S[B1]*A1*-X2	0
Review A-B and Y-X relations (40 trials)	100
6.[a] Probe B-A mutual entailment: S[B1]*A1*-X1 and S[B1]*A1*-B2	100
7. Probe relational reflexivity/irreflexivity	100
8. Probe combinatorial entailment: O[B1]X1-*B2* and O[B2]*B1*-X2	95
Train A-C relations (20 trials)	95
Review A-B, Y-X, and A-C with feedback (24 trials)	100
9. Probe C-A mutual entailment: O[C2]*A1*-X2 and S[C1]*A1*-X2	100
10. Probe combinatorial entailment: S[C2]B1-*B2*	0
O[C1]*C2*-X2	100
Review A-B, Y-X, and A-C with feedback	100
11. Probe combinatorial entailment: [a] S[B2]*C2*-C1	100
and mutual entailment: S[C1]*A1*-X2	100
12. Probe combinatorial entailment: S[C2]B1-*B2* and O[C1]*C2*-X2	100
13. Probe combinatorial entailment: O[C1]B1-*B2* and O[B1]C1-*C2*	0
14. Probe combinatorial entailment: O[C1]B1-*B2* and O[B1]C1-*C2*	0
[Break in sessions. Program modified at this point]	
Review A-B, A-C, and Y-X with feedback (40 trials)	100
15. Probe C-A mutual entailment: O[C2]*A1*-X2 and S[C1]*A1*-X2	100
16. Probe combinatorial entailment: S[C2]B1-*B2*, [a] S[B2]C1-*C2*, S[B1]*C1*-C2, and S[C1]*B1*-B2	100
17. Probe combinatorial entailment: O[C1]*C2*-X1, O[C1]B1-*B2*, and O[B1]C1-*C2*	100

[a] Change of problems normally used in testing.

After C-D training, Subject 1 responded correctly to D-C trials only 75% of the time (Test Block 7 in Figure 4). An error in the computer program allowed progress to the next set of probes, and Subject 1 responded correctly to D-B probes. After a brief review of C-D training, responses to D-C probes for mutual entailment were 100% accurate. The probes for D-B relations were repeated, and responses were again 100% accurate.

Thus, responses to a wide variety of combinations of A, B, and C stimuli were consistent with relational control by SAME and OPPOSITE contexts. The relations described in the introduction to Experiment 1 provide an example. Subjects had a trained history of se-

lecting B1 given A1 only in the presence of SAME, and of selecting B2 given A1 only in the presence of OPPOSITE. Yet when subjects were given the choice of B1 or B2 given C2, in the presence of SAME they now chose B2 100% of the time, not B1.

After initial training of the A-B relations, Subject 2 (see Figure 5 and Table 2) failed to show mutual entailment in the presence of the SAME stimulus. Even after repeated review of the trained A-B relations, mutual entailment given SAME was not demonstrated. At this point the procedure was altered (alteration of procedure is indicated in the tables with an asterisk) to provide additional probes for mutual entailment of the SAME relations. Orig-
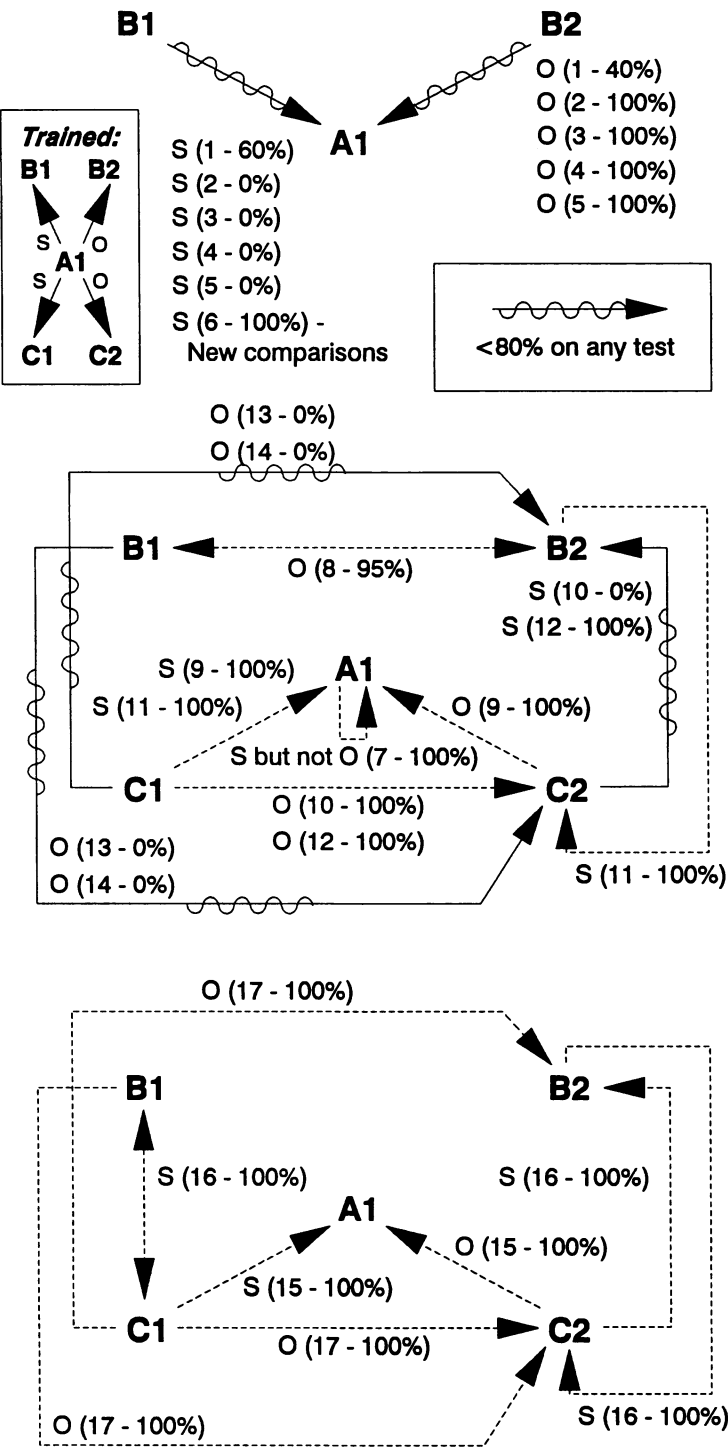
Subject 3 (Pretrained Same/Opposite)

Fig. 6. Testing performance of Subject 3 (pretrained with SAME and OPPOSITE). Dashed lines indicate probes that were above 80% correct, where "correct" is defined as selecting the indicated stimulus. Wavy lines indicate probes were below 80% on at least one of the testing blocks recorded in that section. The letters S and O indicate the relational stimulus presented. Numbers in parentheses indicate the specific testing block (these same numbers are used in Table 3 for cross reference) and the percentage correct. See Table 3 for specific comparison stimuli used and training sequences.

Table 3

Percent of correct responses on training problems and probes for Subject 3 (SAME/OPPOSITE pretrained).

Trained problem or testing probe	% Correct
Train A-B and Y-X relations (40 trials)	90
1. Probe B-A mutual entailment: O[B2]*A1*-X2 and S[B1]*A1*-X2	100
2. Probe relational reflexivity/irreflexivity	100
3. Probe combinatorial entailment: O[B1]X1-*B2* and O[B2]*B1*-X2	100
Train A-C relations (20 trials)	95
Review A-C, A-B, and Y-X relations (24 trials)	100
4. Probe C-A mutual entailment: O[C2]*A1*-X2 and S[C1]*A1*-X2	100
5. Probe combinatorial entailment: S[C2]B1-*B2* and O[C1]*C2*-X2	100
[Break between sessions]	
Train A-B and Y-X relations (40 trials)	95
6. Probe B-A mutual entailment: O[B2]*A1*-X2 and S[B1]*A1*-X2	95
7. Probes for relational reflexivity/irreflexivity	90
8. Probe combinatorial entailment: O[B1]X1-*B2* and O[B2]X2-*B1*	100
Train A-C relations (20 trials)	95
Review A-C, A-B, and Y-X relations (24 trials)	100
9. Probe C-A mutual entailment: O[C2]*A1*-X2 and S[C1]*A1*-X2	100
10. Probe combinatorial entailment: S[C2]B1-*B2,* O[C1]*C2*-X2, O[C1]B1-*B2* and O[B1]C1-*C2*	100
Train C-D relations (20 trials)	90
Review A-B, Y-X, A-C, and C-D with feedback (32 trials)	100
11. Probe D-C mutual entailment: O[D1]C1-*C2* and S[D2]C1-*C2*	94
12. Probe combinatorial entailment: O[D1]B1-*B2*	88
and S[D1]*B1*-B2	63
13. Probe combinatorial entailment: O[A1]D1-*D2*	88
and S[A1]*D1*-D2	100
14. Probe combinatorial entailment: O[D1]B1-*B2* and S[D1]*B1*-B2	100

inally this probe presented S[B1]*A1*-X2. The additional probes used X1 and B2 as incorrect comparisons. This procedure resulted in 100% accurate responses to probes for mutual entailment. Following the training of A-C relations, Subject 2 responded accurately to all probes for combinatorial entailment, except she did not relate C2 and B2 in the presence of SAME. Review of trained relations did not alter this performance. Again, the procedure was altered to provide for additional unreinforced probes (see Table 2 and Figure 5 for details) for combinatorial entailment of the SAME relation. The subject then showed 100% accurate responding. At this point Subject 2 chose to withdraw from the experiment.

Subject 3 (see Figure 6 and Table 3) made 90% or more correct responses on all blocks of training and probes until the D stimuli were added. Subject 3's responses to probes for control by D-B relations were 63% to 88% accurate on the first test (12, Figure 6). After probes for the intermediate A-D relations, D-B relations were 100% accurate.

The roles of specific arbitrary visual stimuli (Figure 2) were randomly reassigned for Subject 4's training and probes (e.g., the stimulus that functioned as A1 for earlier subjects might now be the B2 stimulus). This was done to make sure that some incidental feature of the stimuli had not produced the pattern of control observed with the first 3 subjects. Subject 4 mastered the trained A-B relations quickly and then demonstrated B-A mutual entailment and combinatorial entailment (see Figure 7 and Table 4). After A-C training, Subject 4 failed to pick B2 in probe S[C2]B1-*B2* (Test 5 in Figure 7). A scheduled session break occurred at that point, so in the next experimental session previously trained relations were reviewed. Subject 4 responded correctly to all probes for mutual entailment and combinatorial entailment of the A, B, and C stimuli. Following C-D training, Subject 4 responded incorrectly to probes for D-B relations (Test 12 in Figure 7). After probes for the intermediate A-D relations, his D-B performances rose to 88% correct, and after another test of

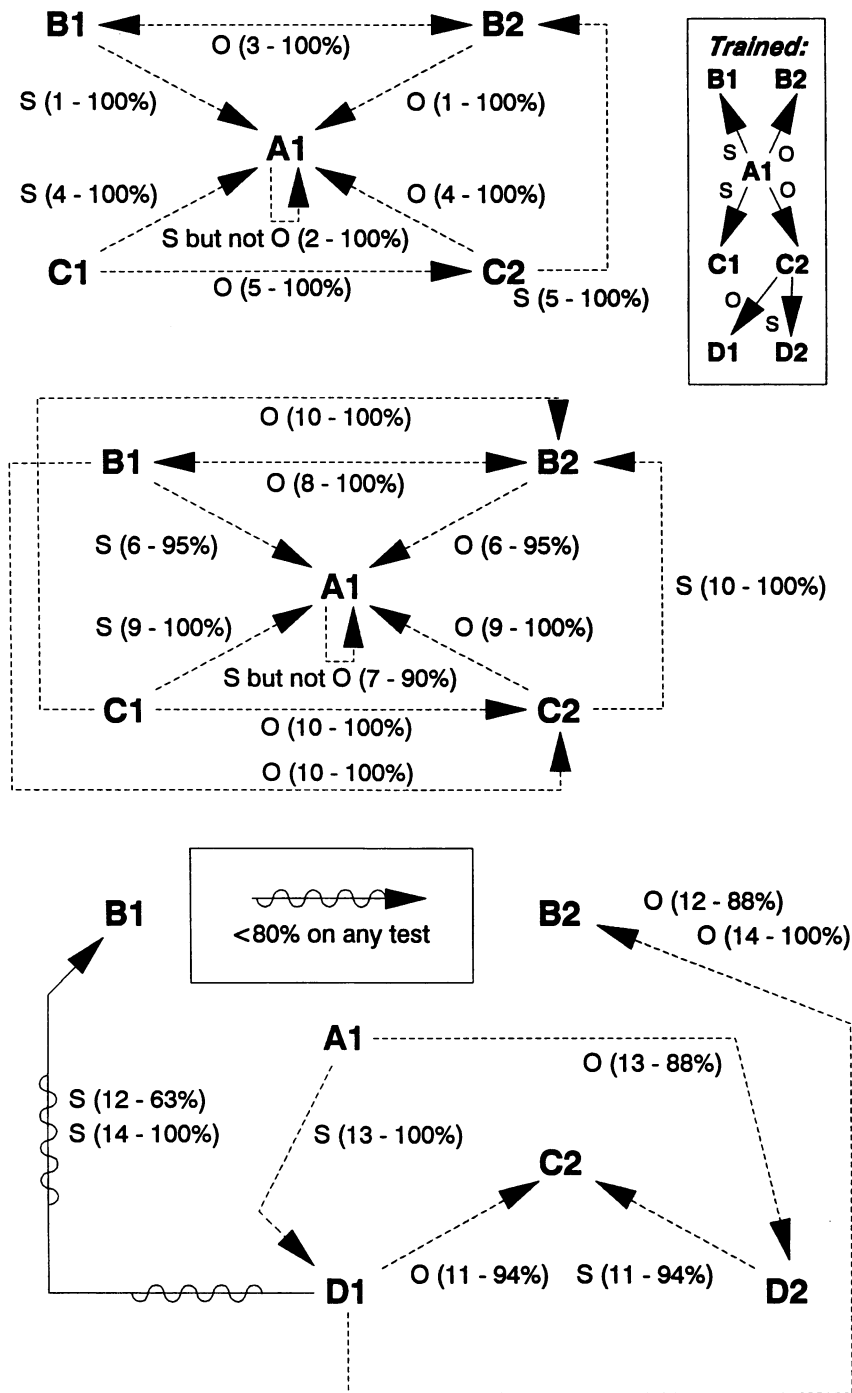# Subject 4 (Pretrained Same/Opposite)
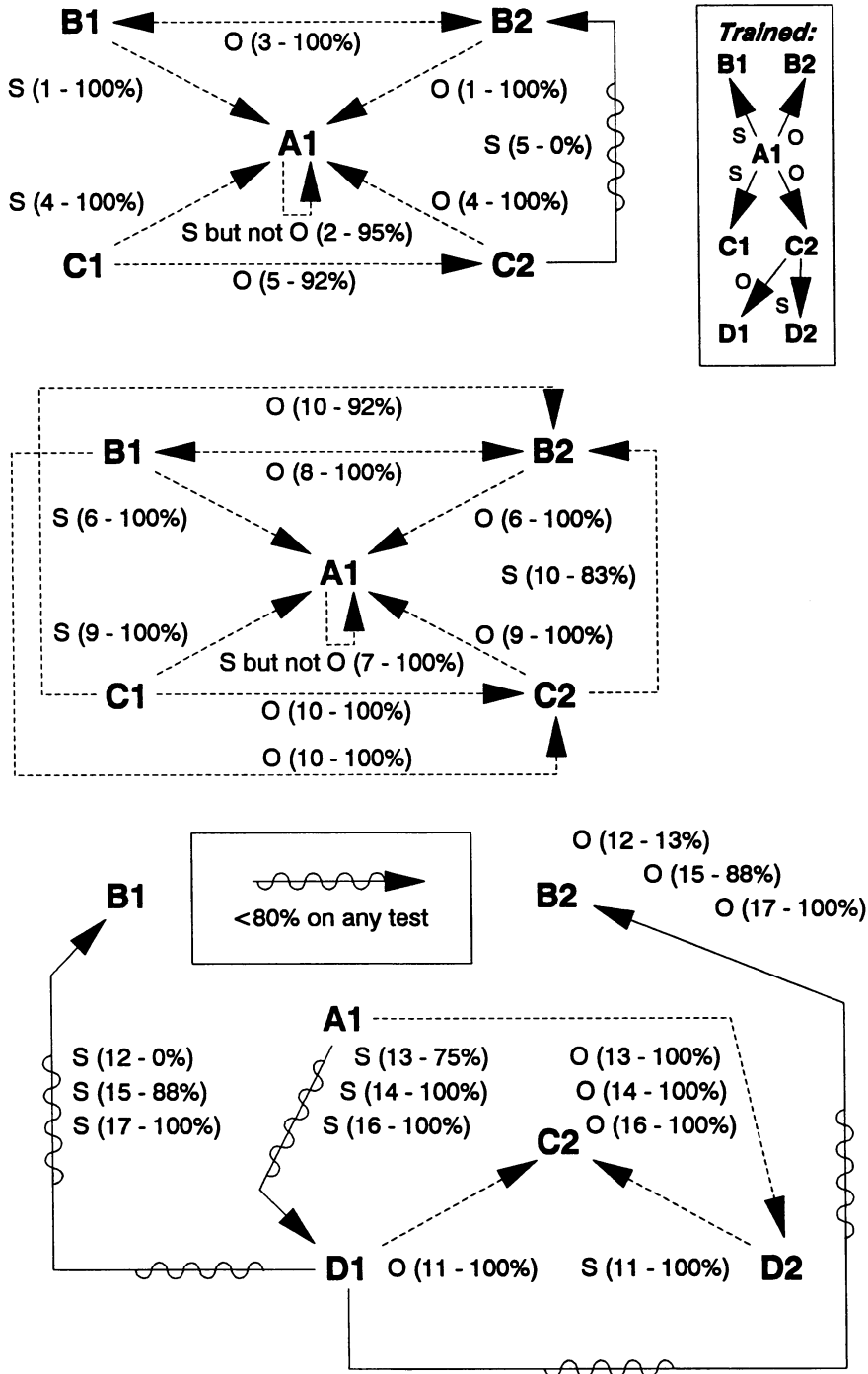
Fig. 7. Testing performance of Subject 4 (pretrained with SAME and OPPOSITE). Dashed lines indicate probes that were above 80% correct, where "correct" is defined as selecting the indicated stimulus. Wavy lines indicate probes were below 80% on at least one of the testing blocks recorded in that section. The letters S and O indicate the relational stimulus presented. Numbers in parentheses indicate the specific testing block (these same numbers are used in Table 4 for cross reference) and the percentage correct. See Table 4 for specific comparison stimuli used and training sequences.

A-D relations, D-B relations were 100% accurate.

Latency of responding. Reaction-time data (Wulfert & Hayes, 1988) have supported the idea that problems increase in difficulty as the number of stimulus relations involved increases (Fields et al., 1984; Sidman, Kirk, & Willson-Morris, 1985; Sidman & Tailby, 1982). In the present study, the fact that two types of relational responding were potentially established complicates the issue. Difficulty of the problems may have been increased in those probes in which the subjects had to apply the relational frames of both same and opposite in arriving at a choice. Reaction-time data, organized by the number of trained and derived stimulus relations and the number of types of relations involved, were examined. For example the probe S[A1]*D1*-D2 involves relations between A-C and C-D. D1 was brought into the network by training O[C2]*D1*-D2, and A1 was related to C2 by training O[A1]C1-C2. So two types of relations (the two trained opposite relations and the derived same relation) and two specific trained relations (A-C and C-D) were required to respond correctly to this probe.

Probes were divided into the following four types: (a) those with one specific stimulus relation and one type of relation (e.g., probes for mutual entailment and probes for relational reflexivity/irreflexivity), (b) those with two trained stimulus relations and two types of relations (e.g., O[B1]*B2*-X1), (c) those with one trained and one derived relation and two types of relations (e.g., O[C1]B1-*B2*), and (d) those involving two derived and one trained relation and two types of relations (e.g., O[D1]B1-*B2*). Latency data were analyzed for all trials in the four types of probes for subjects with complete training histories (1, 3, and 4).

The mean response time increased as probes increased in complexity: 1.8 s, 2.4 s, 3.4 s, and 4.1 s for probe Types (a) through (d) above, respectively. These response latencies were analyzed with a single-factor (type of probe) analysis of variance, and a statistically significant effect was found, $F(3, 830) = 10.83$, $p < .0001$. Differences between groups were examined using Tukey's studentized range (HSD) test. Type (a) probes had significantly ($p < .05$) shorter response times compared to Types (c) and (d). Type (b) probes differed significantly from Type (d).

Table 4

Percentage of correct responses on training problems and probes for Subject 4 (SAME/OPPOSITE pretrained).

Trained problem or testing probe	% Correct
Train A-B and Y-X relations (40 trials)	95
1. Probe B-A mutual entailment:	
O[B2]*A1*-X2 and S[B1]*A1*-X2	100
2. Probe relational reflexivity/irreflexivity	95
3. Probe combinatorial entailment:	
O[B1]X1-*B2* and O[B2]*B1*-X2	100
Train A-C relations (20 trials)	100
Review A-C, A-B, and Y-X relations (24 trials)	100
4. Probe C-A mutual entailment:	
O[C2]*A1*-X2 and S[C1]*A1*-X2	100
5. Probe combinatorial entailment:	
S[C2]B1-*B2*	0
and O[C1]*C2*-X2	92
[Break between sessions]	
Review A-B and Y-X relations with feedback (40 trials)	92
6. Probe B-A mutual entailment:	
O[B2]*A1*-X2 and S[B1]*A1*-X2	100
7. Probes for reflexivity/irreflexivity	100
8. Probe combinatorial entailment:	
O[B1]X1-*B2* and O[B2]*B1*-X2	100
Train A-C relations (20 trials)	100
Review A-C, A-B, and Y-X relations (24 trials)	93
9. Probe C-A mutual entailment:	
O[C2]*A1*-X2 and S[C1]*A1*-X2	100
10. Probe combinatorial entailment:	
S[C2]B1-*B2*	83
and O[C1]*C2*-X2	100
and O[C1]B1-*B2*	92
and O[B1]C1-*C2*	100
Train C-D relations (20 trials)	95
Review A-B, Y-X, A-C, and C-D relations with feedback	100
11. Probe D-C mutual entailment:	
O[D1]*C1*-C2 and S[D2]C1-*C2*	100
12. Probes for combinatorial entailment:	
O[D1]B1-*B2*	13
and S[D1]*B1*-B2	0
13. [a] Probe combinatorial entailment:	
O[A1]D1-*D2*	100
and S[A1]*D1*-D2	75
Review A-B, Y-X, A-C, and C-D relations with feedback (32 trials)	96
14. Probe A-D combinatorial entailment:	
O[A1]D1-*D2* and S[A1]*D1*-D2	100
15. Probe D-B combinatorial entailment:	
O[D1]B1-*B2* and S[D1]*B1*-B2	88
16. Probe combinatorial entailment:	
O[A1]D1-*D2* and S[A1]*D1*-D2	100
17. Probe combinatorial entailment:	
O[D1]B1-*B2* and S[D1]*B1*-B2	100

[a] Change of problems normally used in testing.

Table 5

Percentage of correct responses on training problems and probes for Subject 5 (no pretraining).

Trained problem or testing probe	% Correct
Train A-B and Y-X relations (40 trials)	63
Train A-B and Y-X relations (40 trials)	58
Train A-B and Y-X relations (40 trials)	60
Train A-B and Y-X relations (40 trials)	50
[a] Train A-B relations only (40 trials)	83
[a] Train A-B relations only (40 trials)	100
[a] Train Y-X relations only (40 trials)	93
Train A-B and Y-X relations (24 trials)	63
Train A-B and Y-X relations (24 trials)	100
1. Probe B-A mutual entailment: O[B2]$A1$-X2 and S[B1]$A1$-X2	100
2. Probe reflexivity/irreflexivity	55
Review A-B and Y-X relations with feedback (24 trials)	100
3. Probe reflexivity/irreflexivity	50
Review A-B and Y-x relations with feedback (24 trials)	100
4. Probe reflexivity/irreflexivity	50
[Break between sessions]	
Review A-B and Y-X relations with feedback (24 trials)	100
5. Probe B-A mutual entailment: O[B2]$A1$-X2 and S[B1]$A1$-X2	100
6. Probe reflexivity/irreflexivity	50
Review A-B and Y-X relations with feedback (24 trials)	100
7. Probe combinatorial entailment: O[B1]X1-$B2$ and O[B2]X2-$B1$	50
Review A-B and Y-X relations with feedback (24 trials)	100
8. Probe reflexivity/irreflexivity	50
Review A-B and Y-X relations with feedback (24 trials)	100
9. Probe combinatorial entailment: O[B1]X1-$B2$ and O[B2]X2-$B1$	50
Train A-C relations (20 trials)	95
Review A-B, Y-X, and A-C relations	100
10. Probe C-A mutual entailment: O[C2]$A1$-X2	67
and S[C1]$A1$-X2	100
Review A-B, A-C, and Y-X relations (24 trials)	100
11. Probe C-A mutual entailment: O[C2]$A1$-X2	46
and S[C1]$A1$-X2	92
Train A-C relations (20 trials)	95
12. Probe C-A mutual entailment: O[C2]$A1$-X2	0
and S[C1]$A1$-X2	100
[Program modified to provide different wrong comparison]	
13. Probe C-A mutual entailment: [a] O[C2]$A1$-X1 and S[C1]$A1$-X2	100
14. Probe combinatorial entailment: S[C2]B1-$B2$	0
and O[C1]$C2$-X2, O[C1]B1-$B2$, O[B1]C1-$C2$	100
[Break between sessions]	
Train A-B and Y-X relations (24 trials)	100
15. Probe B-A mutual entailment: O[B2]$A1$-X2	60
and S[B1]$A1$-X2	100
Review A-B and Y-X relations with feedback (24 trials)	100
16. Probe B-A mutual entailment: O[B2]$A1$-X2	70
and S[B1]$A1$-X2	100
Review A-B and Y-X relations with feedback	96
17. Probe B-A mutual entailment: O[B2]$A1$-X2 and S[B1]$A1$-X2	100
Train A-C relations (20 trials)	100
18. Probe C-A mutual entailment: [a] O[C2]$A1$-X1, O[C2]$A1$-X2 and S[C1]$A1$-X2	100
[a] S[C1]$A1$-X1	100
[a] Train S[A1]$B1$-B2, S[A1]$C1$-C2, and S[Y1]$X1$-X2 (30 trials)	100
19. Probe mutual entailment: S[B1]$A1$-X2	100
and S[C1]$A1$-X2	88
and [a] S[B1]$A1$-X1	100
and S[C1]$A1$-X1	88
20. [a] Probe combinatorial entailment: S[B1]$C1$-C2 and S[C1]$B1$-B2	100
[a] Train O[A1]B1-$B2$, O[A1]C1-$C2$, and O[Y1]X1-$X2$ (30 trials)	100

Table 5

(*Continued*)

Trained problem or testing probe	% Correct
21. [a] Probe mutual entailment: O[B2]*A1*-X2	88
and O[C2]*A1*-X2	75
and O[B2]*A1*-X1	88
22. [a] Probe mutual entailment: O[C2]*A1*-X1	100
[a] Train O[A1]B1-*B2*, O[A1]C1-*C2*, and O[Y1]X1-*X2* (30 trials)	96
23. Probe B-A mutual entailment: O[B2]*A1*-X2, O[C2]*A1*-X2, O[B2]*A1*-X1, O[C2]*A1*-X1	100
24. Probe for combinatorial entailment versus conditional equivalence: [a] O[C2]*B1*-(B2)[b] and O[B2]*C1*-(C2)[b]	0
25. Probe combinatorial entailment: O[B1]*B2*-X1	100
and O[B2]*B1*-X2	0
26. Probe combinatorial entailment: S[C2]B1-*B2*	0
and O[C1]*C2*-X2, O[C1]B1-*B2*, and O[B1]C1-*C2*	100
27. Probe reflexivity: S[A1]*A1*-N1	0
and irreflexivity: O[A1]A1-*N2*	100
28. Probe combinatorial entailment: O[B1]*B2*-X1	100
O[B2]*B1*-X2	0
29. Probe combinatorial entailment: S[C2]B1-*B2*	0
O[C1]*C2*-X2, O[C1]B1-*B2*, and O[B1]C1-*C2*	100

[a] Change of problems normally used in training or testing.
[b] Stimulus in parentheses indicates performance expected on Test 24 if conditional equivalence classes had formed. These items were selected 100% of the time.

Subjects Who Received No Pretraining

Trained relations. Subject 5 (see Table 5) had difficulty mastering the initial training of A-B and Y-X training. After four 40-trial blocks, he was responding at chance levels. At that point the procedure was modified so that only A-B relations were trained until a criterion level of mastery was reached. Then Y-X training was conducted, followed by a review of A-B and Y-X problems presented concurrently. It took 328 trials to demonstrate mastery of these trained discriminations.

To avoid Subject 5's problems in mastering the initial A-B and Y-X discriminations, the training procedure was modified for Subject 6 (see Table 6). A-B relations were trained first, followed by Y-X relations and concurrent presentation of both sets of problems. Subject 6 made accurate responses on more than 90% of all trials.

Probes for reflexivity and irreflexivity. Following A-B training, both Subjects 5 and 6 showed mutual entailment (see Figures 8 and 9). On the probes for reflexivity and irreflexivity, Subject 5 selected the novel stimulus instead of the comparison that was identical to the sample given both SAME and OPPO-

SITE. Subject 6 did so given SAME. Review of the trained relations did not produce a change in response pattern for either subject.

When pretrained subjects did not show correct responding, they were given an expanded set of relevant probes. This same tactic was tried with Subject 6. She was given two probes for reflexivity (S[A1]*A1*-N1 and S[A1]*A1*-N2) and two similar probes for irreflexivity (O[A1]A1-*N1* and O[A1]A1-*N2*). Subject 6 developed a consistent pattern of responding that resulted in making four different responses to the four probes. This pattern is as follows (with Subject 6's choice of comparison in parentheses): S[A1]A1-(N1), O[A1]A1-(N2), S[A1](A1)-N2, O[A1](A1)-N1.

Probes for mutual entailment. Subject 6 responded correctly to all mutual entailment probes. Subject 5 initially showed mutual entailment with B-A but not C-A probes. An expanded set of probes resulted in C-A mutual entailment (see Table 5).

Combinatorial entailment within sets of comparisons. Pretrained subjects learned that B1 is the same as A1, and B2 is the opposite of A1. They then responded consistently to the probe O[B1]X1-*B2*. Subject 5 initially failed to show this pattern of control for B1 and B2,

Subject 5 - No Pretraining of Relational Stimuli

O (7 - 50%)
O (9 - 50%)

B1 ◄—————————► **B2**

S (1 - 100%)   O (1 - 100%)
S (5 - 100%)   O (5 - 100%)

A1

S (10 - 100%)   O (10 - 67%)
S (11 - 92%) **C1**   O (11 - 46%) **C2**
S (12 - 100%)   O (12 - 0%)
S (13 - 100%)   O (13 - 100%) -
                                            New comparisons

S but not O (2 - 50%)
S but not O (3 - 50%)
S but not O (4 - 50%)
S but not O (6 - 50%)
S but not O (8 - 50%)

~~~► <80% on any test

O (14 - 100%)

B1   **B2** ◄ S (14 - 0%)

S (15 - 100%)
S (16 - 100%)   O (15 - 60%)
S (17 - 100%)   O (16 - 70%)
S (19 - 100%) **A1** O (17 - 100%)

S (18 - 100%)   O (18 - 100%)
S (19 - 88%)

C1   O (14 - 100%)   **C2**

O (14 - 100%)

Trained:

B1   B2

S \ / O
A1
S / \ O

C1   C2

O (26 - 100%)
O (29 - 100%)

O (25 - 100%)
O (28 - 100%)

O (25 - 0%)
O (28 - 0%)

B1   **B2** ◄

O (21 - 88%)
O (22 - 88%)
S (20 - 100%)   O (23 - 100%)   S (26 - 0%)
              A1 O (21 - 75%)   S (29 - 0%)
                      O (22 - 100%)
              S (27 - 0%) O (23 - 100%)
              O (27 - 100%)

C1   **C2**

O (26 - 100%)   O (26 - 100%)
O (29 - 100%)   O (29 - 100%)

O (24 - 0%) - see Table 5
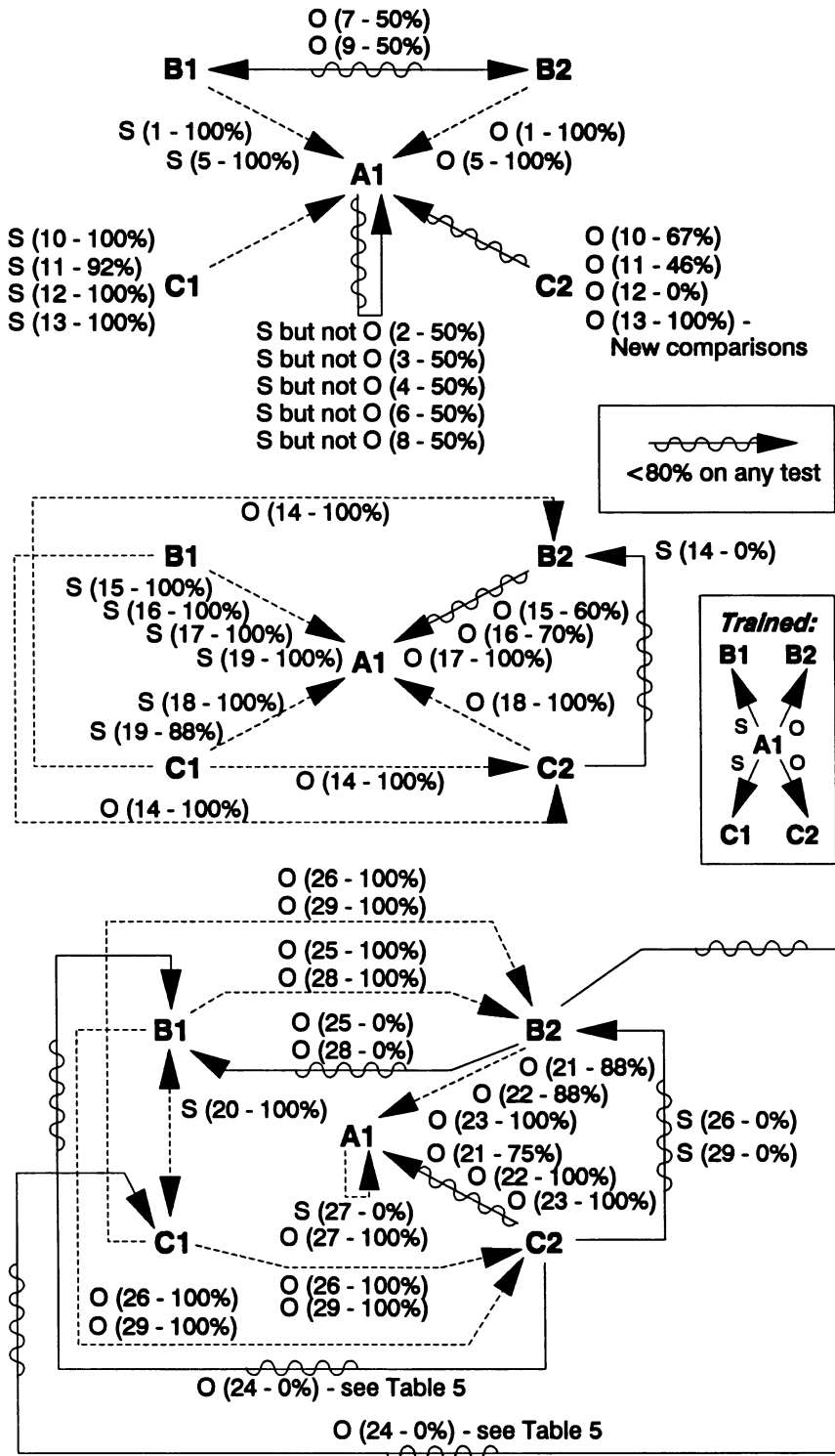
O (24 - 0%) - see Table 5

Table 6

Percentage of correct responses on training problems and probes for Subject 6 (no pretraining).

Trained problem or testing probe	% Correct
Train S[A1]*B1*-B2 and O[A1]B1-*B2* (20 trials)	95
Train S[Y1]*X1*-X2 and O[Y1]X1-*X2* (20 trials)	95
Train all A-B and Y-X relations (40 trials)	100
1. Probe B-A mutual entailment: O[B2]*A1*-X2 and S[B1]*A1*-X2	100
2. Probe reflexivity: S[A1]*A1*-N1	0
and irreflexivity: O[A1]A1-*N2*	100
Review A-B and Y-X relations with feedback (24 trials)	100
3. Probe combinatorial entailment: O[B1]X1-*B2* and O[B2]*B1*-X2	95
4. Probe B-A mutual entailment: O[B2]*A1*-X2 and S[B1]*A1*-X2	100
5. Probe reflexivity: S[A1]*A1*-N1	0
and irreflexivity: O[A1]A1-*N2*	100
Train A-C relations (20 trials)	100
Review A-B, Y-X, and A-C with feedback	100
6. Probe B-A mutual entailment: O[B2]*A1*-X2 and S[B1]*A1*-X2	100
7. Probe combinatorial entailment: S[C2]B1-*B2*	0
and O[C1]C2-X2	100
8. Probe combinatorial entailment: O[C1]B1-*B2* and O[B1]C1-*C2*	100
Review A-B, Y-X, and A-C with feedback (24 trials)	100
9. Probe combinatorial entailment: O[C1]B1-*B2* and O[B1]C1-*C2*	100
[Break between sessions]	
Review A-B and Y-X relations with feedback (24 trials)	100
10. Probe B-A mutual entailment: O[B2]*A1*-X2 and S[B1]*A1*-X2	100
11. Probe reflexivity: S[A1]*A1*-N1	0
and irreflexivity: O[A1]A1-*N2*	100
[a] Probe reflexivity: S[A1]*A1*-N2	100
and [a] irreflexivity: O[A1]A1-*N1*	0
Review A-B and Y-X relations with feedback	100
12. Probe combinatorial entailment: O[B1]X1-*B2*	100
and O[B2]X2-*B1*	0
Review A-B and Y-X relations with feedback (24 trials)	100

Table 6

(*Continued*)

Trained problem or testing probe	% Correct
13. Probe combinatorial entailment: O[B1]X1-*B2*	100
and O[B2]X2-*B1*	0
Train A-C relations (20 trials)	95
Review A-B, Y-X, and A-C relations (24 trials)	100
14. Probe C-A mutual entailment: O[C2]*A1*-X2 and S[C1]*A1*-X2	100
15. Probe combinatorial entailment: S[C2]B1-*B2*	0
and [a] S[C1]*B1*-B2, [a] S[B1]*C1*-C2	100
and [a] S[B2]C1-*C2*	0
Review A-B, Y-X, and A-B relations (24 trials)	100
16. Probe combinatorial entailment: S[C2]B1-*B2*	0
and O[C1]C2-X2, O[C1]B1-*B2*	100
and O[B1]C1-*C2*	0
17. Probe combinatorial entailment: S[C2]B1-*B2*	0
and O[C1]C2-X2	100
18. Probe combinatorial entailment: O[C1]B1-*B2* and O[B1]C1-*C2*	100

[a] Change of problems normally used in testing.

but this pattern of responding was observed in later sessions. Subject 6 responded to these probes similarly to the pretrained subjects.

Combinatorial entailment across stimulus sets. Following A-C training, subjects were given three probes (S[C2]C1-*B2*, O[C1]B1-*B2*, and O[B1]C1-*C2*) that tested for combinatorial entailment. The control subjects answered correctly on the two OPPOSITE problems but even though trained relations were repeatedly reviewed and expanded probe sets were given, they consistently responded to the probe S[C2]C1-*B2* by selecting the comparison C1. This overall pattern makes sense because each of these performances in the presence of SAME and OPPOSITE could have been established in the experimental subjects (with pretraining) via relations in the other context. For example, the sameness between B2 and C2 may have been established in the experimental subjects
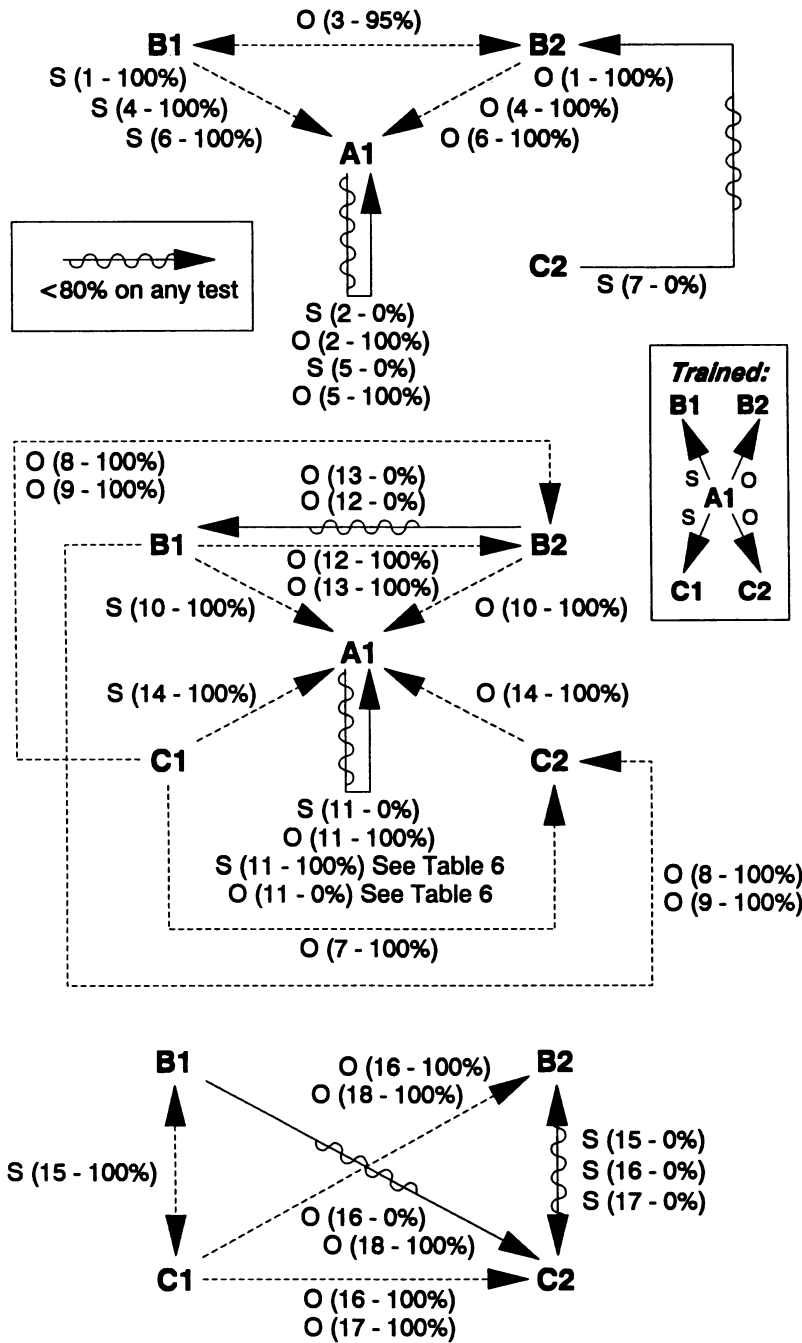

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Fig. 8. Testing performance of Subject 5 (no pretraining on relational stimuli). Dashed lines indicate probes that were above 80% correct, where "correct" is defined as selecting the indicated stimulus. Wavy lines indicate probes were below 80% on at least one of the testing blocks recorded in that section. The letters S and O indicate the relational stimulus presented. Numbers in parentheses indicate the specific testing block (these same numbers are used in Table 5 for cross reference) and the percentage correct. See Table 5 for specific comparison stimuli used and training sequences.

Subject 6 - No Pretraining of Relational Stimuli

Fig. 9.   Testing performance of Subject 6 (no pretraining on relational stimuli). Dashed lines indicate probes that were above 80% correct, where "correct" is defined as selecting the indicated stimulus. Wavy lines indicate probes were below 80% on at least one of the testing blocks recorded in that section. The letters S and O indicate the relational stimulus presented. Numbers in parentheses indicate the specific testing block (these same numbers are used in Table 6 for cross reference) and the percentage correct. See Table 6 for specific comparison stimuli used and training sequences.

via a combination of two relations of opposition (O[A1]B1-*B2* and O[A1]C1-*C2*). For the control subjects, OPPOSITE and SAME were simply arbitrary stimuli and presumably did not bring distinct kinds of relational responding to bear on the situation. Thus, the subjects seemed simply to pick a comparison that had been reinforced in the given context. For example, the control subjects never had a history of reinforcement for selecting C2 in the presence of the SAME stimulus but did for C1 (S[A1]*C1*-C2).

Subjects Who Received Same/Different Pretraining

Same/different subjects received the same arbitrary matching-to-sample training as is shown in Figure 2, except that DIFFERENT was pretrained and used in the place of OPPOSITE. It was not clear whether subjects given same/different pretraining would perform like the same/opposite subjects. On the one hand, the combinatorial entailment of a difference relation seems distinct from that of an opposition relation. If B is different from A and C is different from A, the relation between B and C seems unspecified except that both are different from A. In a two-choice matching-to-sample format, it was not clear what subjects would do. Given a choice such as D[C2]B1-B2, the difference relation might yield the same performances as the opposite relation (namely, the selection of B2) via exclusion. Essentially, the DIFFERENT pretrained subjects might show responding like that seen with OPPOSITE if subjects treat the difference relation like the "not" relation of formal logic, commonly symbolized by the tilde, ~. The "logical not" relation has these properties: 1. a = ~~a; 2. if a = ~b, then b = ~a; 3. if a = ~b, and b = ~c, then a = c. Opposition has a similar quality when arbitrarily applied. In lay language, words are opposites if they refer to conditions equidistant on either side of an arbitrarily defined midpoint of a quantitative continuum for a specific quality (e.g., "warm" and "cool" are often relative to the temperature of a human as the midpoint). When stripped of any qualitative or quantitative information, opposition has no midpoint and collapses into the "logical not" relation.

Pretraining. The subjects who received same/different pretraining required the following number of 40-trial blocks to reach the criterion level of performance: Subject 7, 11; Subject 8, 9; and Subject 9, 8. Because the performance of Subject 7 was unlike the other 2, he will be considered separately.

A-B training and testing, Subjects 8 and 9. Both Subject 8 (see Table 7 and Figure 10) and Subject 9 (see Table 8 and Figure 11) showed rapid mastery of A-B training. On probes for mutual entailment, relational reflexivity/irreflexivity, and combinatorial entailment, both subjects demonstrated criterion-level performance on the initial block of trials.

A-C training and testing, Subjects 8 and 9. Subjects 8 and 9 showed rapid mastery of A-C training and C-A mutual entailment. Subject 9 responded 100% correctly to all of the probes for combinatorial entailment. Subject 8 failed to show the derived relations, so he was given an expanded set of probes (see Table 7) and quickly responded correctly. These subjects were not exposed to C-D training or debriefed at this point; instead they returned to begin Experiment 2 in their next session.

Subject 7. The performance of Subject 7 was unlike that of any other subject (see Table 9 and Figure 12). Following pretraining, the initial A-B and Y-X training was accomplished in two blocks of trials, and probes for B-A mutual entailment were at the criterion level. On the first probe for relational reflexivity/irreflexivity, Subject 7 failed to show control by the relational stimuli for the same and different relations. Reviewing the same/different pretraining and reviewing the initial A-B training failed to produce consistent responding on these probes. Finally, the problems S[A1]*A1*-N2 and D[A1]A1-*N2* were explicitly trained using feedback. Even after reflexive and irreflexive choices were made reliably, Subject 7 failed to show control by any of the derived relations. He should have been able to respond correctly to the probes D[B1]B1-*B2* and D[B2]*B1*-B2 if the relational stimuli had come to control making same and different choices. A-C training was begun because alternative training and testing options had been exhausted. Subject 7 mastered A-C relations in one block of trials, reviewed all trained relations, and then showed C-A mutual entailment. Even with reviews of trained relations and expanded probe sets, however, Subject 7 failed to show combinatorial entailment.

During debriefing, Subject 7 described an elaborate system he had used to remember the

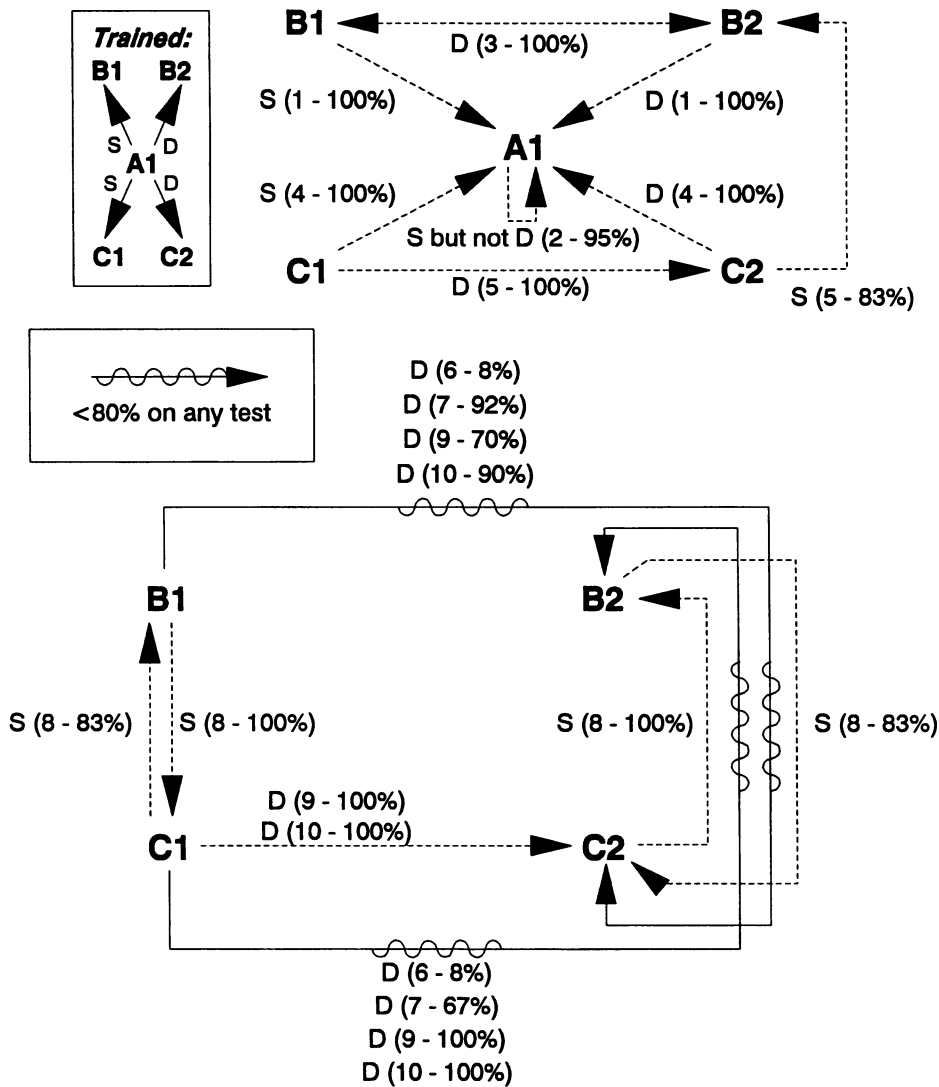## Subject 8 (Pretrained Same/Different)

Fig. 10. Testing performance of Subject 8 (pretrained with SAME and DIFFERENT). Dashed lines indicate probes that were above 80% correct, where "correct" is defined as selecting the indicated stimulus. Wavy lines indicate probes were below 80% on at least one of the testing blocks recorded in that section. The letters S and D indicate the relational stimulus presented. Numbers in parentheses indicate the specific testing block (these same numbers are used in Table 7 for cross reference) and the percentage correct. See Table 7 for specific comparison stimuli used and training sequences.

trained relations. It involved finding some detail of the stimuli that could be related to each other. In the presence of one relational stimulus, one detail of the sample and comparison stimuli was used; with the other relational stimulus, a different detail was used. He explained that the SAME stimulus meant "choose the same one," whereas the DIFFERENT stimulus meant "choose the other one"—referring to the same or different formal details.

Table 7

Percentage of correct responses on training problems and probes for Subject 8, Experiment 1 (SAME/DIFFERENT pretraining).

Trained problem or testing probe	% Correct
Train A-B and Y-X relations (40 trials)	88
Train A-B and Y-X relations (40 trials)	98
1. Probe B-A mutual entailment:	
D[B2]*A1*-X2 and S[B1]*A1*-X2	100
2. Probe reflexivity/irreflexivity	95
3. Probe combinatorial entailment:	
D[B1]X1-*B2* and D[B2]*B1*-X2	100
Train A-C relations (20 trials)	90
Review A-B, Y-X, and A-C relations	
with feedback (24 trials)	100
4. Probe C-A mutual entailment:	
D[C2]*A1*-X2 and S[C1]*A1*-X2	100
5. Probe combinatorial entailment:	
S[C2]B1-*B2*	83
and D[C1]*C2*-X2	100
6. Probe combinatorial entailment:	
D[C1]B1-*B2*, D[B1]C1-*C2*	8
Review A-B, Y-X, and A-C relations	
with feedback (24 trials)	100
7. Probe combinatorial entailment:	
D[C1]B1-*B2*	67
and D[B1]C1-*C2*	92
Review A-B, Y-X, and A-C relations	
with feedback (24 trials)	100
8. Probe combinatorial entailment:	
S[C2]B1-*B2* and [a] S[B1]*C1*-C2	100
and [a] S[B2]C1-*C2* and [a] S[C1]*B1*-B2	84
9. Probe combinatorial entailment:	
D[B1]C1-*C2*	70
and D[C1]*C2*-X2 and D[C1]B1-*B2*	100
10. Probe combinatorial entailment:	
D[B1]C1-*C2*	90
and D[C1]*C2*-X2 and D[C1]B1-*B2*	100

[a] Change of problems normally used in testing.

Table 8

Percentage of correct responses on training problems and probes for Subject 9, Experiment 1 (SAME/DIFFERENT pretraining).

Trained problem or testing probe	% Correct
Train A-B and Y-X relations (40 trials)	100
1. Probe B-A mutual entailment:	
D[B2]*A1*-X2 and S[B1]*A1*-X2	98
2. Probe reflexivity/irreflexivity	100
3. Probe combinatorial entailment:	
D[B1]X1-*B2* and D[B2]*B1*-X2	100
Train A-C relations (20 trials)	100
Review A-B, Y-X, and A-C relations	
with feedback	100
4. Probe C-A mutual entailment:	
D[C2]*A1*-X2 and S[C1]*A1*-X2	100
5. Probe combinatorial entailment:	
S[C2]B1-*B2* and D[C1]*C2*-X2	100
6. Probe combinatorial entailment:	
D[C1]B1-*B2*, D[B1]C1-*C2*	100

The relational stimuli apparently exerted contextual control—but over formal selection criteria, not over arbitrary matching.

DISCUSSION

The performance of Subjects 5 and 6 (the subjects without pretraining establishing distinct relational histories for SAME and OPPOSITE) showed patterns much like those in the equivalence literature. It is well known that conditional equivalence classes can emerge that arrange subsets of stimuli into classes given second-order conditional stimuli (e.g., Bush, Sidman, & de Rose, 1989; Wulfert & Hayes, 1988). For Subjects 5 and 6, A1, B1, and C1 entered into an equivalence class in the presence of SAME, showing B-A and C-A mutual entailment and B-C combinatorial entailment. A1, B2, and C2 also entered into an equivalence class, but in the presence of OPPOSITE. For example, given O[C2]B1-B2, these subjects chose B2. They had learned to pick both B2 and C2 given A1 in the presence of OPPOSITE, and thus B2 and C2 were in an equivalence class given OPPOSITE.

All of the pretrained subjects except Subject 7 showed patterns of responding that go beyond equivalence or conditional equivalence. Probes for mutual entailment showed bidirectional stimulus functions, as with the control subjects but tests for combinatorial entailment showed different results. Subject 1, for example, selected an opposite of an opposite only in the presence of SAME and not OPPOSITE (the C2-B2 relation—Test 5 in Figure 4); an opposite of an opposite of an opposite was selected only given OPPOSITE and not SAME (the D1-B2 relation—Tests 8 and 10 in Figure 4). An opposite of an opposite of a same was selected only given SAME (the D1-B1 relation—Tests 8 and 10 in Figure 4).

Some of the subjects required retraining or special patterns of testing, but the final patterns were quite similar across subjects. Of course, networks such as these give rise to a large number of possible alternative interpretations of the results—a topic that will be addressed later. Of more immediate interest are
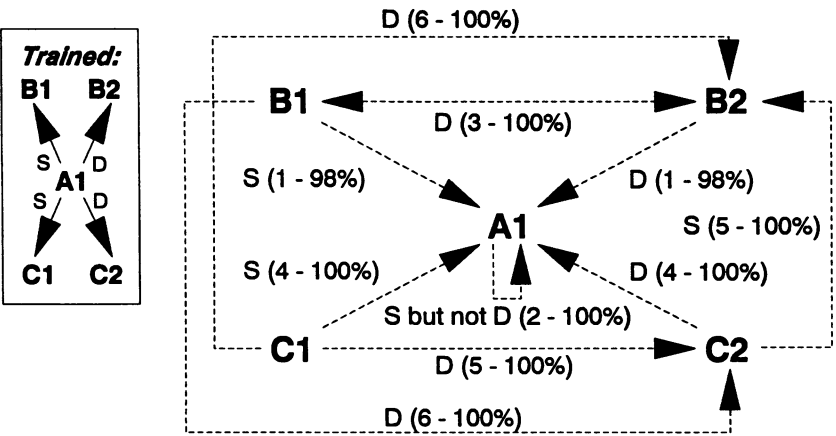
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EXPERIMENT 1   *Subject 9 (Pretrained Same/Different)*

Subject 9 (Pretrained Same/Different/Opposite)
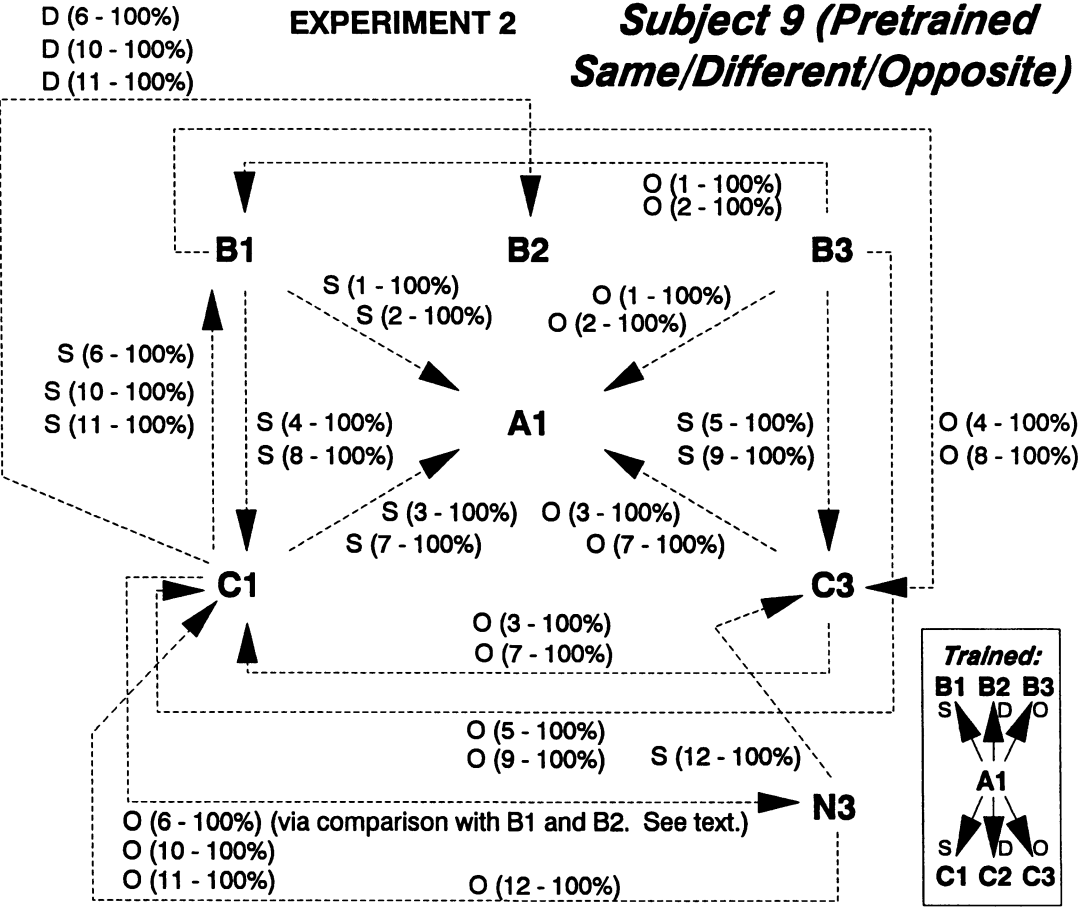
EXPERIMENT 2

Fig. 11. Testing performance of Subject 9 (pretrained with SAME and DIFFERENT) in Experiment 1 (top half) and her performance in Experiment 2 after being pretrained with SAME, DIFFERENT, and OPPOSITE (bottom half). Dashed lines indicate probes that were above 80% correct, where "correct" is defined as selecting the

the similar results between subjects who received same/different and same/opposite pretraining. On the basis of the subjects' histories with the relational stimuli, they may simply have learned that in the context of one relational stimulus responding on the basis of equivalence was reinforced, whereas in the context of the other relational stimulus responding on the basis of nonequivalence was reinforced. This would show conditional control over equivalence per se (not to be confused with conditional equivalence classes), but it does not necessitate an appeal to relational frames. If equivalence is a basic behavioral process, only conditional control over that process is needed as an explanation.

In Experiment 1, however, only two relational stimuli and two comparisons were used. This causes analytic ambiguities in certain key areas. Consider the probe for combinatorial entailment S[B2]C1-*C2*. If B2 is the opposite of A1 and C2 is the opposite of A1, then B2 and C2 are the same. Subjects given same/opposite pretraining would be expected to select C2, which they did. The subjects who received same/different pretraining had been trained to select B2 and C2 as being different from A1. In the abstract, this leaves the relationship between B2 and C2 undefined; they are both different from A1, but they could be either the same as or different from one another. The fact that there were only two comparisons made available another source of control, however, in the actual matching-to-sample task. C1, A1, and B1 had entered into an equivalence class in the presence of SAME for the SAME/DIFFERENT subjects (see Figures 10 and 11). B2 was not in that class, and thus given B2 as a sample in the presence of SAME, subjects could merely exclude C1 and select C2. These kinds of problems with two-choice procedures in equivalence research have been previously noted (Sidman, 1987).

To address this analytic ambiguity, a second experiment was conducted in which three relational stimuli were trained: SAME, OPPOSITE, and DIFFERENT. Distinct and predictable patterns of responding among three separate relations cannot as readily be explained on the basis of only two principles: equivalence and nonequivalence. The use of these three relations also allowed for the distinction between mere difference and oppositeness.

EXPERIMENT 2

The intent of Experiment 2 was to bring three relations—same, opposite, and different—under stimulus control. Both opposite and different are irreflexive relations, but have different implications for a network of relations.

METHOD

Subjects, Apparatus, and Stimuli

The subjects for this experiment were Subject 8 and Subject 9 who had received SAME/DIFFERENT pretraining in Experiment 1. The apparatus and stimuli were the same as in Experiment 1 except that provision was now made to present three different relational stimuli and two or three comparisons, depending on the specific problem. Three comparisons were needed in certain types of probes to reduce the applicability of simple forms of exclusion. Two comparisons were used in some training and probe items to distinguish the different and opposite relations.

Procedure

The general network of trained and tested relations is shown in Figure 13. The plan for the training and probes is given in Figure 14. Subject 8 and Subject 9 were first given pretraining with SAME and OPPOSITE identical to that used with other subjects in Experiment 1. Subjects had already learned S[A1]*B1*, D[A1]*B2*, S[A1]*C1*, and D[A1]*C2* in Experiment 1. They were now given the same training as the same/opposite subjects in Experiment 1 except that the B2 and C2 stimuli in Experiment 1 (what will be called B3 and C3, respectively, in this experiment) were re-

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indicated stimulus. Wavy lines indicate probes were below 80% on at least one of the testing blocks recorded in that section. The letters S, D, and O indicate the particular relational stimulus presented. Numbers in parentheses indicate the specific testing block (these same numbers are used in Tables 8 and 11 for cross reference) and the percentage correct. See Tables 8 and 11 (for Experiments 1 and 2, respectively) for specific comparison stimuli used and training sequences.

Table 9

Percentage of correct responses on training problems and probes for Subject 7 (SAME/DIF-FERENT pretraining).

Trained problem or testing probe	% Correct
Train A-B and Y-X relations (40 trials)	80
Train A-B and Y-X relations (40 trials)	100
1. Probe B-A mutual entailment: D[B2]*A1*-X2 and S[B1]*A1*-X2	75
Review A-B and Y-X relations with feedback (24 trials)	100
2. Probe B-A mutual entailment: D[B2]*A1*-X2 and S[B1]*A1*-X2	95
3. Probe reflexivity/irreflexivity	0
[a] Review pretraining block for same/different control	95
4. Probe reflexivity/irreflexivity	0
Review A-B and Y-X relations with feedback (24 trials)	96
5. Probe reflexivity/irreflexivity	0
[a] Review pretraining block for same/different control	83
[a] Review a pretraining block for same/different control	100
6. [a] Probe reflexivity/irreflexivity	100
Train A-B and Y-X relations (40 trials)	95
7. Probe B-A mutual entailment: D[B2]*A1*-X2 and S[B1]*A1*-X2	95
8. Probe reflexivity/irreflexivity	0
[a] Review a pretraining block for same/different control	96
9. Probe reflexivity/irreflexivity	0
[a] Review a pretraining block for same/different control	96
10. Probe reflexivity/irreflexivity	0
[a] Review pretraining block for same/different control	96
11. Probe reflexivity/irreflexivity	0
[a] Explicitly train reflexive/irreflexive choices using the experimental stimuli	96
12. Probe B-A mutual entailment: D[B2]*A1*-X2 and S[B1]*A1*-X2	100
13. Probe reflexivity/irreflexivity	0
[a] Train reflexivity/irreflexivity with experimental stimuli	70
14. Probe reflexivity/irreflexivity	85
15. Probe combinatorial entailment: D[B1]X1-*B2* and D[B2]X2-*B1*	0
Review A-B and Y-X relations with feedback	100
16. Probe combinatorial entailment: D[B1]X1-*B2* and D[B2]X2-*B1*	0
[a] Train reflexivity/irreflexivity with experimental stimuli	92
[a] Train reflexivity/irreflexivity with experimental stimuli	100
17. Probe reflexivity/irreflexivity	100
18. Probe combinatorial entailment: D[B1]X1-*B2* and D[B2]X2-*B1*	0
Train A-C relations	100
Review A-B, Y-X, and A-C relations with feedback (24 trials)	100
19. Probe C-A mutual entailment: D[C2]*A1*-X2 and S[C1]*A1*-X2	100
20. Probe combinatorial entailment: S[C2]B1-*B2*	0
and D[C1]*C2*-X2	8
Review A-B, Y-X, and A-C relations with feedback (24 trials)	100
21. Probe combinatorial entailment: S[C2]B1-*B2*, D[C1]*B2*-X2	0
22. Probe combinatorial entailment: S[C2]B1-*B2*	17
and S[B2]C1-*C2*	0
and S[B1]*C1*-C2	50
and S[C1]*B1*-B2	0
Review A-B, Y-X, and A-C relations with feedback (24 trials)	100
23. Probe combinatorial entailment: S[C2]B1-*B2*, [a] S[B2]C1-*C2*, [a] S[B1]*C1*-C2, and S[C1]*B1*-B2	0

[a] Change of problems normally used in training or testing.

placed with new figures because the old ones had already been related as different from A1 for these subjects (in the problems D[A1]*B2* and D[A1]*C2*). This essentially added the following relations to those trained in Experiment 1: O[A1]*B3* and O[A1]*C3*. Subjects were also given a review of the same/different training that they had received in Experiment 1.

As in Experiment 1, probe blocks consisted of equal numbers of probe items and previously trained problems presented without reinforcement. Order of the probes was random-
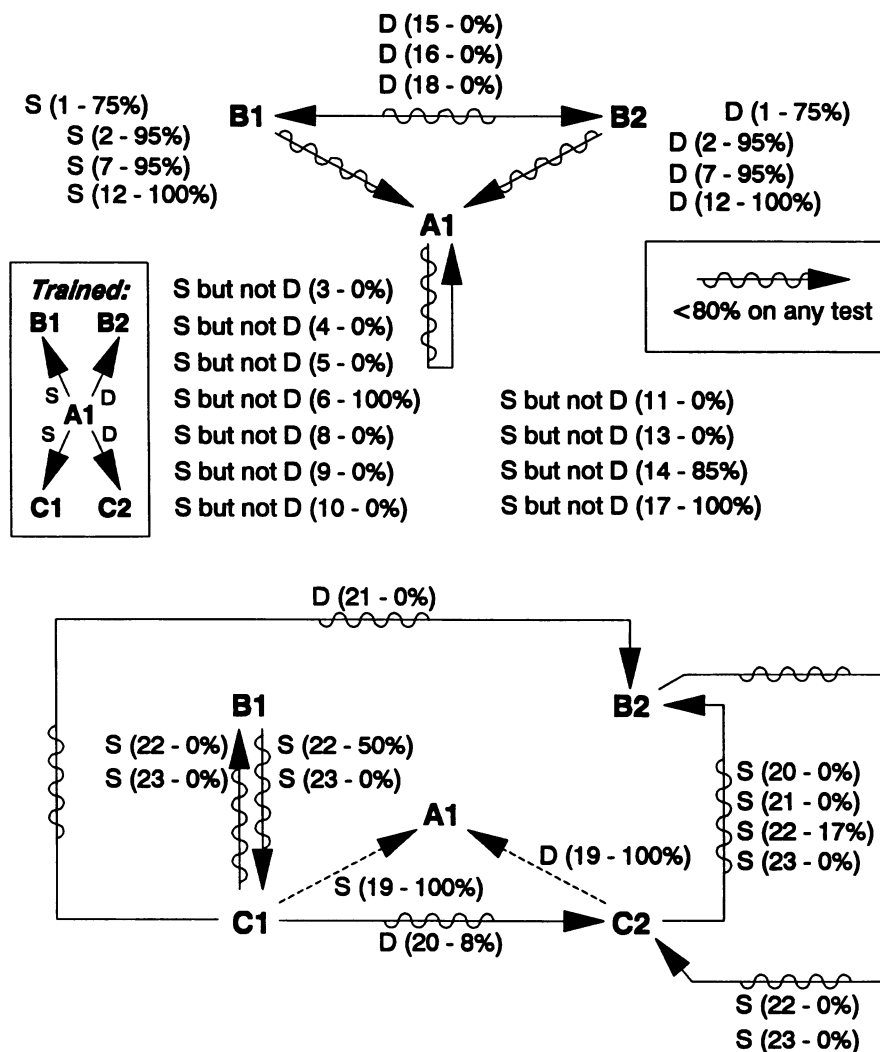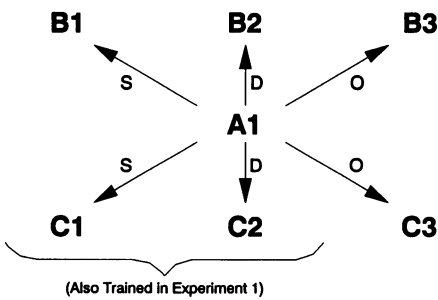
Subject 7 (Pretrained Same/Different)

D (15 - 0%)
D (16 - 0%)
D (18 - 0%)

S (1 - 75%)   **B1** ◄─────► **B2**   D (1 - 75%)
S (2 - 95%)   D (2 - 95%)
S (7 - 95%)   D (7 - 95%)
S (12 - 100%)   **A1**   D (12 - 100%)

Trained:	S but not D (3 - 0%)
B1 **B2**	S but not D (4 - 0%)
S \ / D	S but not D (5 - 0%)
A1	S but not D (6 - 100%)
S / \ D	S but not D (8 - 0%)
C1 **C2**	S but not D (9 - 0%)
	S but not D (10 - 0%)

S but not D (11 - 0%)
S but not D (13 - 0%)
S but not D (14 - 85%)
S but not D (17 - 100%)

〜〜〜► <80% on any test

D (21 - 0%)

B1   **B2**

S (22 - 0%) ↕ S (22 - 50%)   S (20 - 0%)
S (23 - 0%)   S (23 - 0%)   S (21 - 0%)
                   A1   S (22 - 17%)
                                      S (23 - 0%)
              S (19 - 100%)   D (19 - 100%)

C1 ─────────────► **C2**
         D (20 - 8%)

S (22 - 0%)
S (23 - 0%)

Fig. 12. Testing performance of Subject 7 (pretrained with SAME and DIFFERENT). Dashed lines indicate probes that were above 80% correct, where "correct" is defined as selecting the indicated stimulus. Wavy lines indicate probes were below 80% on at least one of the testing blocks recorded in that section. The letters S and D indicate the relational stimulus presented. Numbers in parentheses indicate the specific testing block (these same numbers are used in Table 9 for cross reference) and the percentage correct. See Table 9 for specific comparison stimuli used and training sequences.

ized with one exception noted below. On each trial the placement of comparisons (left, center, or right) was randomly determined. A-B training was given in blocks of 27 trials (nine for each problem). The probes for mutual entailment and the probe for combinatorial entailment (Probes K, L, and M in Figure 14) were presented in blocks of 27 probes combined with 27 trials in which the trained A-B problems were presented in extinction. A-C training was conducted in blocks of 27 trials, and then A-B and A-C training was reviewed with each problem presented three times. Probes N, O, and P, Probes Q and R, and Probes S and T (see Figure 14) were each presented sequentially as blocks.

Trained Relations

(Also Trained in Experiment 1)

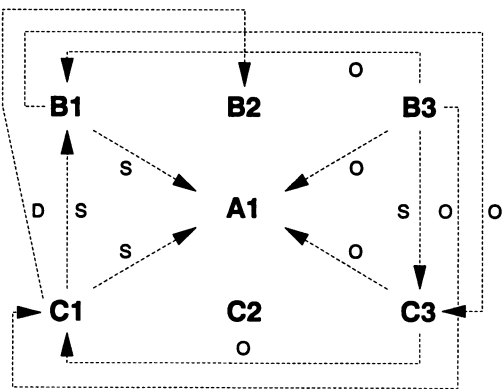## Basic Set of Tested Derived Relations

Fig. 13.   Basic network of relations trained and tested in Experiment 2. Solid lines indicate trained discriminations, and dashed lines indicate assessment of relations by probe items. Letters S, D, and O indicate relational stimuli SAME, DIFFERENT, and OPPOSITE. Training and testing differed for some subjects.

Some of the first 10 types of probes (Probes K through M and N through T in Figure 14) provide additional evidence over the results of Experiment 1, primarily because they assess whether both O and D worked in Experiment 1 via exclusion. In Probe R, for example, subjects could exclude C1 (because C1 and B1 are in an equivalence class given S but not O), but that would not demand that subjects pick C3 instead of C2. Similarly, in Probe T (O[B3]*C1*-C2-C3) subjects could avoid C3 on the basis of "B3 not A1 not C3," but on that basis there would be no reason to select C1 over C2 (responding to neither had been reinforced given O).

The most important evidence came from Probes U, V, and W. The subject was pre-

EXPERIMENT 2

Train:	(E)	(F)	(G)
	S	O	D
	A1	A1	A1
	B1 B2 B3	B1 B2 *B3*	B1 *B2*

Probe for mutual entailment		Probe for combinatorial entailment
(K)	(L)	(M)
S	O	O
B1	B3	B3
A1 B2 B3	*A1* B2	*B1* B2

Train:	(H)	(I)	(J)
	S	O	D
	A1	A1	A1
	C1 C2 C3	C1 C2 *C3*	C1 *C2*

Probe for mutual entailment		Probe for combinatorial entailment
(N)	(O)	(P)
S	O	O
C1	C3	C3
A1 C2 C3	*A1* C2	*C1* C2

Probe for combinatorial entailment

(Q)	(R)	(S)	(T)
S	O	S	O
B1	B1	B3	B3
C1 C2 C3	C1 C2 *C3*	C1 C2 *C3*	*C1* C2 C3

Probe for combinatorial entailment

(U)	(V)	(W)
S	D	O
C1	C1	C1
B1 B2 N3	B1 *B2* N3	B1 B2 *N3*

Probes for combinatorial entailment (Subject 9 only)

(X)	(Y)
O	S
N3	N3
C1 C2 C3	C1 C2 *C3*

Fig. 14.   The basic training and testing sequence for Experiment 2. Specific sequences varied for specific subjects. Letters in parentheses indicate probes.

sented with two familiar comparisons (B1 and B2) and a novel stimulus (N3) as a comparison. Selecting B1 in S[C1]*B1*-B2-N3 (Probe U) can be derived from combinatorial entailment of the same relation. In the probe, D[C1]B1-*B2*-N3 (Probe V), picking B2 comes from combinatorial entailment of the relations same and different. Subjects were trained that B2 is different from A1, and C1 is the same as A1. Thus B2 is different from C1. Responding in the last probe, O[C1]B1-B2-*N3* (Probe W), assessed whether OPPOSITE controls the same kind of responding as DIFFERENT. If not, and if responding is based on combinatorial entailment of the relations same and opposite, then neither B1 nor B2 can be a correct choice. B1 and C1 are the same as A1 and B2 is different from A1, but not opposite of A1, and thus not of C1. The only choice left is the novel stimulus. If OPPOSITE merely controls nonequivalence, then either B2 or N3 is a possibility. The predicted pattern of responding to Probe W (O[C1]B1-B2-*N3*) depends on control by the extended network of relations. The subject can select the novel stimulus (N3) by eliminating the other comparisons as incorrect. Thus, for Probes U, V, and W, the order of presentation was not randomized; subjects responded to Probes U and V at least three times each before being exposed to Probe W.

Additional probes for Subject 9. If subjects did pick N3 in Probe W, then N3 might enter into the network of relations as the opposite of C1 and therefore the same as C3. Subject 9 was given an additional probe for mutual entailment (O[N3]*C1*-C2-C3) and a probe for combinatorial entailment (S[N3]C1-C2-*C3*) to see if N3 had entered into the network of relations via testing alone.

RESULTS AND DISCUSSION

Subject 8

After same/opposite pretraining and a review of same/different pretraining, Subject 8 (see Table 10) mastered the A-B relations in one block of 27 trials. There are some initial problems with probes for mutual entailment and combinatorial entailment, but after four blocks of probes responding was at criterion levels (see Figure 15a).

Training A-C relations required only one block of 27 trials, but Subject 8 failed to show combinatorial entailment of responding with

Probe R (O[B1]C1-C2-*C3*). Review of trained relations and further probe trials failed to alter the pattern. On Probes U, V, and W, Subject 8 responded at criterion levels on the second presentation (see Figure 15b). On the fourth presentation of these probes, he sometimes selected comparison N3 when given Probe V (D[C1]B1-*B2*-N3). It should be noted that in terms of control by arbitrary relations, this is not an incorrect response. If the previous exposure to N3 established it as the opposite of C1, then N3 is also different from C1 (this is one reason that exposure to Probe W was reserved until after Probes U and V). On three further exposures to this set of probes, Subject 8's responses followed the predicted pattern on 100% of the trials. Finally, the experimenter noticed a clue to Subject 8's failure to respond correctly on Probe R. When the previously trained relations were presented in extinction, Subject 8 sometimes made erroneous responses to the previously trained problem O[A1]C1-C2-*C3*. A set of probes that included O[A1]C1-C2-*C3*, S[B1]*A1*-B2-B3, and O[B1]C1-C2-*C3* were added. Immediate increase in correct responding to Probe R was observed, to 100% after two blocks of these probes.

Subject 9

Subject 9's performance was characterized by extremely accurate responding (see Table 11). Her data are displayed side by side with Experiment 1 data (see Figure 11) to enable a fuller grasp of her total performance. After same/opposite pretraining and a review of the same/different pretraining, A-B training was accomplished with only one wrong response. A-C training was also accomplished with only one wrong response. Responses to all probes were 100% correct. Probes U, V, and W were given Subject 9 three times even though she was 100% accurate on the first presentation in order to assess her consistency of responding. Subject 9 was given the two additional probes to see if N3 entered into the network of relations, and again all responses were consistent with the predicted pattern.

GENERAL DISCUSSION

Previous work has shown that nonarbitrary stimulus relations can be brought under contextual control and applied to novel sets of formally related stimuli (Lowenkron, 1989).

Table 10

Percentage of correct responses to training and probe trials for Subject 8, Experiment 2 (SAME/DIFFERENT/OPPOSITE pretraining).

Trained problem or testing probe	% Correct
Train A-B relations (with same, different, and opposite conditional stimuli for 27 trials)	97
1. Probe B-A mutual entailment: S[B1]*A1*-B2-B3	100
and combinatorial entailment: O[B3]*B1*-B2	33
Review A-B relations with feedback (18 trials)	100
2. Probe B-A mutual entailment: S[B1]*A1*-B2-B3	100
and combinatorial entailment: O[B3]*B1*-B2	0
Review A-B relations with feedback (18 trials)	100
3. Probe B-A mutual entailment: S[B1]*A1*-B2-B3	100
and O [B3] *A1*-B2	78
and combinatorial entailment: O[B3]*B1*-B2	100
Review A-B relations with feedback (18 trials)	100
4. Probe B-A mutual entailment: S[B1]*A1*-B2-B3 and O[B3]*A1*-B2	100
and combinatorial entailment: O[B3]*B1*-B2	100
Train A-C relations (27 trials)	97
Review A-B and A-C relations with feedback (24 trials)	100
5. Probe C-A mutual entailment: S[C1]*A1*-C2-C3 and O[C3]*A1*-C2	100
6. Probe combinatorial entailment: O[C3]*C1*-C2, S[B1]*C1*-C2-C3	100
and O[B1]C1-C2-*C3*	11
Review A-B and A-C relations with feedback (24 trials)	100
7. Probe C-A mutual entailment: S[C1]*A1*-C2-C3 and O[C3]*A1*-C2	100
and combinatorial entailment: O[C3]*C1*-C2	100
8. Probe combinatorial entailment: S[B1]*C1*-C2-C3	100
and O[B1]C1-C2-*C3*	0
[Break between sessions]	
Review pretraining for same, different, and opposite conditional stimuli	100
Train A-B relations (27 trials)	100
9. Probe B-A mutual entailment: S[B1]*A1*-B2-B3	100
and O[B3]*A1*-B2	89
and combinatorial entailment: O[B3]*B1*-B2	100
Train A-C relations (27 trials)	100
Review A-B and A-C relations with feedback (24 trials)	100
10. Probe C-A mutual entailment: S[C1]*A1*-C2-C3 and O[C3]*A1*-C2	100
and combinatorial entailment: O[C3]*C1*-C2	100
11. Probe combinatorial entailment: S[B1]*C1*-C2-C3	89
and O[B1]C1-C2-*C3*	0
Review A-B and A-C relations with feedback (24 trials)	100
12. Probe combinatorial entailment: S[B1]*C1*-C2-C3	89
and O[B1]C1-C2-*C3*	0
13. Probe combinatorial entailment: S[B3]C1-C2-*C3*	89
and O[B3]*C1*-C2-C3	44
Review A-B and A-C relations with feedback	100
14. Probe combinatorial entailment: S[B3]C1-C2-*C3*, O[B3]*C1*-C2-C3	89
15. Probe combinatorial entailment: S[B3]C1-C2-*C3*	89
and O[B3]*C1*-C2-C3	100
16. Probe combinatorial entailment: S[C1]*B1*-B2-N3	88
and D[C1]B1-*B2*-B3	75
and O[C1]B1-B2-*N3*	88
Review A-B and A-C relations with feedback	100
17. Probe combinatorial entailment: S[C1]*B1*-B2-N3	100
and D[C1]B1-*B2*-B3	88
and O[C1]B1-B2-*N3*	100
18. Probe combinatorial entailment: S[B1]*C1*-C2-C3	100
and O[B1]C1-C2-*C3*	11
Review A-B relations with feedback (24 trials)	100
19. Probe B-A mutual entailment: S[B1]*A1*-B2-B3 and O[B3]*A1*-B2	100
and combinatorial entailment: O[B3]*B1*-B2	100
Train A-C relations (27 trials)	100

Table 10

(*Continued*)

Trained problem or testing probe	% Correct
20. Probe C-A mutual entailment: S[C1]*A1*-C2-C3 and O[C3]*A1*-C2	100
and combinatorial entailment: O[C3]*C1*-C2	100
21. Probe combinatorial entailment: O[C3]*C1*-C2, S[B1]*C1*-C2-C3	100
and combinatorial entailment: O[B1]C1-C2-*C3*	0
22. Probe combinatorial entailment: S[B3]C1-C2-*C3*, O[B3]*C1*-C2-C3	100
23. Probe combinatorial entailment: S[C1]*B1*-B2-N3	100
and D[C1]B1-*B2*-B3	50
and O[C1]B1-B2-*N3*	100
Review A-B and A-C relations with feedback	100
24. Probe combinatorial entailment: S[C1]*B1*-B2-N3, D[C1]B1-*B2*-N3, O[C1]B1-B2-*N3*	100
25. Probe B-A mutual entailment: S[B1]*A1*-B2-B3 and O[B3]*A1*-B2	100
and combinatorial entailment: O[B3]*B1*-B2	100
26. Probe C-A mutual entailment: S[C1]*A1*-C2-C3	88
and O[C3]*A1*-C2	100
and combinatorial entailment: O[C3]*C1*-C2	100
27. Probe combinatorial entailment: O[C3]*C1*-C2, S[B1]*C1*-C2-C3	100
and combinatorial entailment: O[B1]C1-C2-*C3*	0
28. Probe combinatorial entailment: O[C3]*C1*-C2, S[B1]*C1*-C2-C3	100
and O[B1]C1-C2-*C3*	0
29. Probe combinatorial entailment: S[B3]C1-C2-*C3*	100
and O[B3]*C1*-C2-C3	89
30. Probe combinatorial entailment: S[C1]*B1*-B2-N3, D[C1]B1-*B2*-B3, O[C1]B1-B2-*N3*	100
31. Probe B-A mutual entailment: S[B1]*A1*-B2-B3 and O[B3]*A1*-B2	100
and combinatorial entailment: O[B3]*B1*-B2	100
32. [a] Probe previously trained relation: O[A1]C1-C2-*C3*	100
and mutual entailment: S[B1]*A1*-B2-B3	100
and combinatorial entailment: O[B1]C1-C2-*C3*	89
33. Probe combinatorial entailment: O[C3]*C1*-C2, S[B1]*C1*-C2-C3, O[B1]C1-C2-*C3*	100
34. Probe combinatorial entailment: S[B3]C1-C2-*C3*	100
and O[B3]*C1*-C2-C3	89
35. Probe combinatorial entailment: S[C1]*B1*-B2-N3, D[C1]B1-*B2*-B3	100
and O[C1]B1-B2-*N3*	89

[a] Change of problems normally used in testing.

This finding was essentially replicated in the pretraining phases of both experiments. The present study seems to be the first to show that such contextual control over relational responding can extend to stimuli not related by virtue of their formal properties. Subjects showed patterns of performance that were consistent with control by the relations of same, opposite, and different in an arbitrary matching-to-sample context. These performances instantiate "arbitrarily applicable relational responding" in the sense that the relational responses involved were brought to bear on items by virtue of contextual cues to do so (in the present case, SAME, OPPOSITE, and DIFFERENT). In short, the present results demonstrate the existence of relational frames. A wide number of alternative explanations could be provided, however.

Alternative Accounts

Even in simplified relational networks such as the ones used here, the complexity of possible derived relations and unintended sources of control is very great. For any given set of probes it is relatively easy to identify a source of control that could explain these results without an appeal to arbitrarily applicable relational responding. We will briefly consider two alternative accounts.

Direct S+ and S− control by the relational stimuli. Performance on many specific probes could be explained on the basis of S+ and S− control by the relational stimuli. Consider, for example, Probe W in Experiment 2 (see Figure 14). Subjects were confronted with O[C1]B1-B2-N3. B1 and B2 had been S− stimuli in the presence of O, and selection of

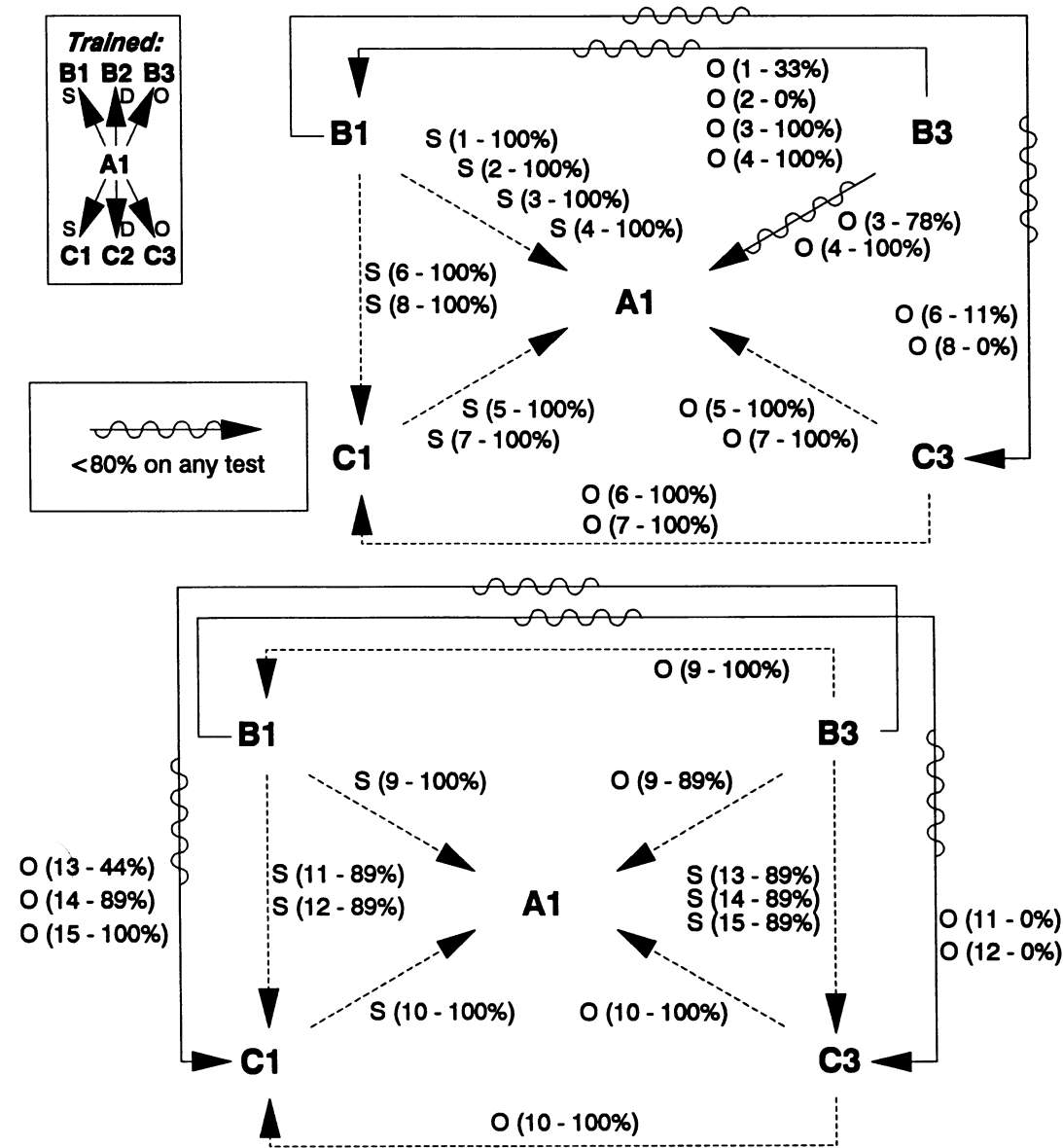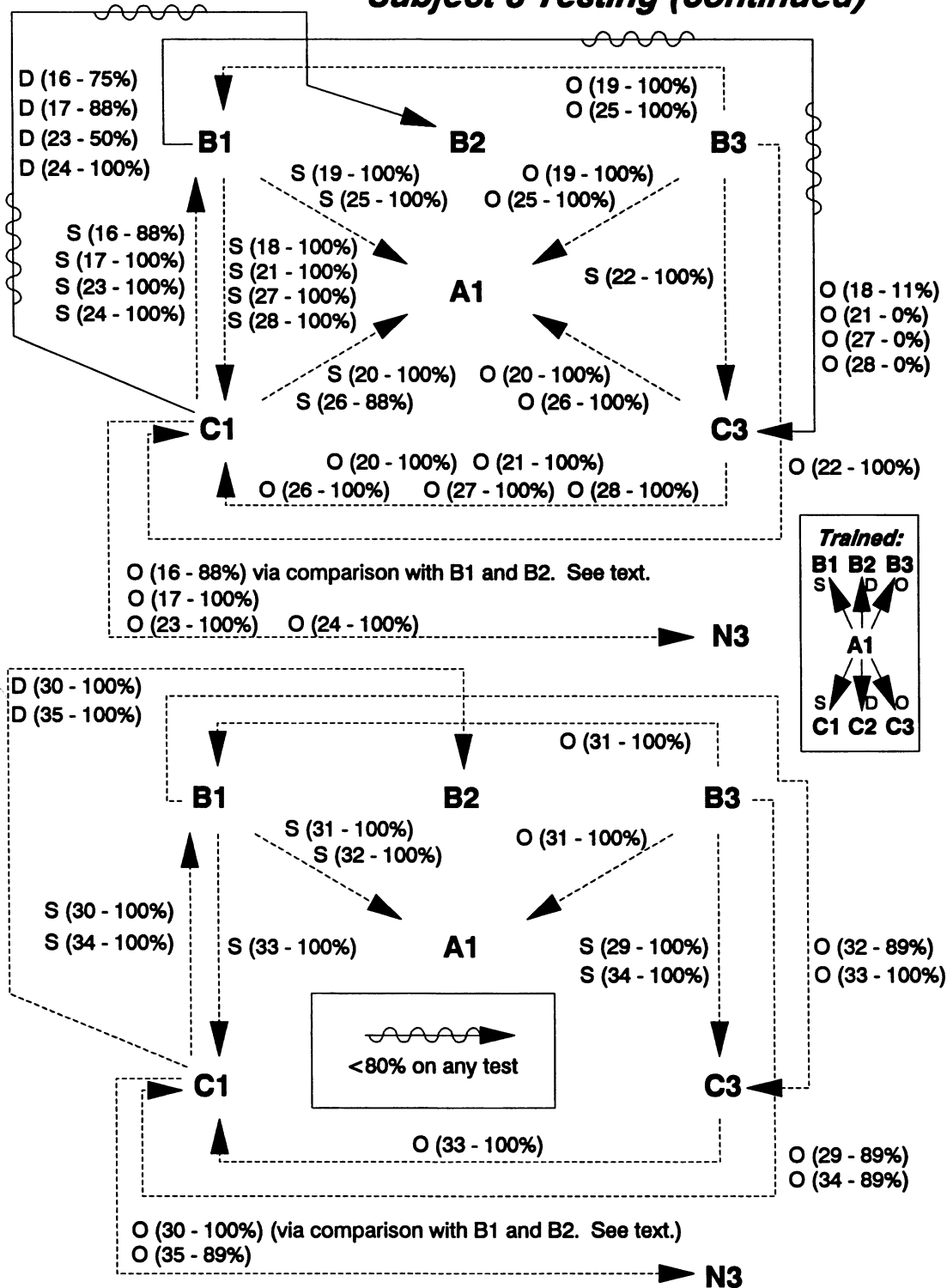## *Subject 8 (Pretrained Same/Opposite/Different)*

Fig. 15a. Testing performance of Subject 8 (pretrained with SAME, DIFFERENT, and OPPOSITE) in Experiment 2. Dashed lines indicate probes that were above 80% correct, where "correct" is defined as selecting the indicated stimulus. Wavy lines indicate probes were below 80% on at least one of the testing blocks recorded in that section. The letters S, O, and D indicate the particular relational stimulus presented. Numbers in parentheses indicate the specific testing block (these same numbers are used in Table 10 for cross reference) and the percentage correct. See Table 10 for specific comparison stimuli used and training sequences.

→

Fig. 15b. Continuation of testing performance of Subject 8 (pretrained with SAME, DIFFERENT, and OPPOSITE) in Experiment 2. Dashed lines indicate probes that were above 80% correct, where "correct" is defined as selecting the indicated stimulus. Wavy lines indicate probes were below 80% on at least one of the testing blocks recorded in that section. The letters S, O, and D indicate the particular relational stimulus presented. Numbers in

Subject 8 Testing (continued)

D (16 - 75%)
D (17 - 88%)
D (23 - 50%)
D (24 - 100%)

O (19 - 100%)
O (25 - 100%)

B1   **B2**   **B3**

S (19 - 100%)   O (19 - 100%)
S (25 - 100%)   O (25 - 100%)

S (16 - 88%)
S (17 - 100%)
S (23 - 100%)
S (24 - 100%)

S (18 - 100%)
S (21 - 100%)
S (27 - 100%)
S (28 - 100%)

S (22 - 100%)

A1

O (18 - 11%)
O (21 - 0%)
O (27 - 0%)
O (28 - 0%)

S (20 - 100%)   O (20 - 100%)
S (26 - 88%)   O (26 - 100%)

C1   **C3**

O (20 - 100%)   O (21 - 100%)
O (26 - 100%)   O (27 - 100%)   O (28 - 100%)

O (22 - 100%)

O (16 - 88%) via comparison with B1 and B2. See text.
O (17 - 100%)
O (23 - 100%)   O (24 - 100%)

N3

Trained:
B1 B2 B3
S   D   O

A1

S   D   O
C1 C2 C3

D (30 - 100%)
D (35 - 100%)

O (31 - 100%)

B1   **B2**   **B3**

S (31 - 100%)   O (31 - 100%)
S (32 - 100%)

S (30 - 100%)
S (34 - 100%)

S (33 - 100%)   **A1**   S (29 - 100%)
S (34 - 100%)

O (32 - 89%)
O (33 - 100%)

<80% on any test

C1   **C3**

O (33 - 100%)

O (29 - 89%)
O (34 - 89%)

O (30 - 100%) (via comparison with B1 and B2. See text.)
O (35 - 89%)

N3

parentheses indicate the specific testing block (these same numbers are used in Table 10 for cross reference) and the percentage correct. See Table 10 for specific comparison stimuli used and training sequences. See also Figure 15a.

Table 11

Percentage of correct responses on training and probes for Subject 9, Experiment 2 (SAME/DIFFERENT/OPPOSITE pretraining).

Trained problem or testing probe	% Correct
Train A-B relations (with same, different, and opposite conditional stimuli for 27 trials)	97
1. Probe B-A mutual entailment: S[B1]*A1*-B2-B3 and O[B3]*A1*-B2	100
and combinatorial entailment: O[B3]*B1*-B2	100
Train A-C relations (27 trials)	97
Review A-B and A-C relations with feedback	100
[Break between sessions]	
Review same/different pretraining for 24 trials	
Review same/opposite pretraining for 24 trials	
Review A-B relations (with same, different, and opposite conditional stimuli)	100
2. Probe B-A mutual entailment: S[B1]*A1*-B2-B3 and O[B3]*A1*-B2	100
and combinatorial entailment: O[B3]*B1*-B2	100
Train A-C relations (20 trials)	100
Review A-B and A-C relations with feedback	100
3. Probe C-A mutual entailment: S[C1]*A1*-C2-C3 and O[C3]*A1*-C2	100
and combinatorial entailment: O[C3]*C1*-C2	100
4. Probe combinatorial entailment: S[B1]*C1*-C2-C3, O[B1]C1-C2-*C3*	100
5. Probe combinatorial entailment: S[B3]C1-C2-*C3*, O[B3]*C1*-C2-C3	100
6. Probe combinatorial entailment: S[C1]*B1*-B2-N3, D[C1]B1-*B2*-N3, O[C1]B1-B2-*N3*	100
7. Probe C-A mutual entailment: S[C1]*A1*-C2-C3 and O[C3]*A1*-C2	100
and combinatorial entailment: O[C3]*C1*-C2	100
8. Probe combinatorial entailment: S[B1]*C1*-C2-C3, O[B1]C1-C2-*C3*	100
9. Probe combinatorial entailment: S[B3]C1-C2-*C3*, O[B3]*C1*-C2-C3	100
10. Probe combinatorial entailment: S[C1]*B1*-B2-N3, D[C1]B1-*B2*-N3, O[C1]B1-B2-*N3*	100
11. Probe combinatorial entailment: S[C1]*B1*-B2-N3, D[C1]B1-*B2*-N3, O[C1]B1-B2-*N3*	100
12. [a] Probe combinatorial entailment: S[N3]C1-C2-*C3*, O[N3]*C1*-C2-C3	100

[a] Change of problems normally used in testing.

N3 could thus be explained on that basis. But if such an explanation is adopted, performance on Probe M (Figure 14) would have to be explained, because subjects selected B1 given O[B3]B1-B2. Many of the other probes would also predict different performances than those actually seen if mere S+ and S− control were the issue. An account in terms of S+ and S− control does not fit with all of the testing results and is inadequate on these grounds.

Equivalence and exclusion. Many of the probe performances can be explained on the basis of equivalence and exclusion. Explaining Experiment 2 strictly in these terms is difficult because three distinct patterns of performance were shown. This seems at least to require an appeal to higher order forms of exclusion, in which stimuli selected by virtue of exclusion in the presence of DIFFERENT were themselves excluded in the presence of OPPOSITE. Such an analysis would be complicated but is surely not impossible.

Consider the wide variety of qualitative relations that can be modeled with digital computers. At the level of circuitry, all can be reduced to combinations of "on" and "off." Equivalence and exclusion have this same on/off quality and presumably could be used by behavioral theorists to model a wide variety of complex cognitive relations, including opposite and different. In computer modeling of complex relations, however, very many combinations of on and off can be necessary, and the same may be true for models of complex relations based on equivalence and exclusion alone.

Conversely, arbitrarily applicable relational responding may itself be taken to be the basic unit. In that case, both exclusion and equivalence would be viewed as examples of a broader behavioral process. The results of the present experiments fit with this idea, but they do not eliminate the alternatives. Selecting among these and other alternatives will re-

quire better behavior-analytic methods, and the present study may be of some use in this area.

Implications for Equivalence

The present studies have several implications for the study of equivalence.

Compound stimuli. In their study of conditional equivalence classes, Bush et al. (1989) pointed out that apparent second-order conditional stimuli may have entered into a compound with the sample and thereby exerted control over conditional discriminations. The procedure in the present study rules out control of responding by a compound stimulus and gives unequivocal evidence for second-order conditional control. Consider the probe S[C2]B1-*B2*. Pretrained subjects in Experiment 1 reliably selected the comparison B2, as predicted by a relational response account. There were no training items that used C2 as a sample, and all previous probes with C2 as a sample had been presented with the OPPOSITE stimulus as the relational stimulus. Further, there were no training items in which B2 was the reinforced comparison selection when the SAME stimulus was presented as the relational stimulus. The relational stimulus and the sample must have functioned independently to produce the pattern of responding observed in the present study. This provides support for Sidman's development of the four- and five-term contingency nomenclature (Sidman, 1986), but only if these terms are available to control distinct responses. For example, although the SAME, OPPOSITE, and DIFFERENT stimuli can be thought of as fifth terms in contingencies, their effects were distinct.

Contextual control over equivalence and nonequivalence. For pretrained subjects, one relational stimulus reliably resulted in the choice of reflexive or equivalent sample-comparison selections. The other relational stimuli resulted in irreflexive or nonequivalent choices. At the least, this shows that forming equivalence itself can be brought under contextual control. In the presence of one relational stimulus, a given comparison would enter into an equivalence relationship with a sample. In the presence of the other relational stimulus, the same comparison would be excluded from the class of stimuli equivalent to that same sample.

This finding is distinct from demonstrations of conditional equivalence classes (e.g., Wulfert & Hayes, 1988) that involve the composition of equivalence classes, not the presence or absence of equivalence.

To the extent that these data strengthen the plausibility of the relational frame account, there are other implications for issues of contextual control of equivalence. Arbitrarily applicable relational responding must be able to be brought to bear by the context, not solely by formal properties of the items being related. What contextual factors might be involved in equivalence research?

Probably the most fundamental language process is that of naming. Of importance to the present argument is the development of coordination between the productive and receptive aspects of naming. For example, children are taught to name an object and also to orient toward a named object. Each discrimination may be trained unidirectionally at first, but the overall performance occurs in consistent contexts in which the bidirectional relation is applicable. (Parenthetically, coordinated name–object and object–name relations are not strictly symmetrical because the responses involved differ. This may be resolved if the child has a generalized imitative repertoire that enables the repetition of sounds that are heard. Thus, the symmetrical version of productive naming is: hear name—orient toward object [given A then B]; when oriented toward object—hear name [then say the name heard] [given B then A produce A].)

If a child with an extensive naming history is taught "This is your boat," contextual cues (such as the word "is," or the naming context more generally) reliably predict that if this is a boat, a boat is this. Thus, the child may now orient toward the boat when asked "Where is your boat?" without direct training to do so because contextual cues brought a frame of coordination to bear on the trained relation.

The naming situation is similar to the matching-to-sample preparation usually used in experimental studies of equivalence. In natural language circumstances children are often asked, for example, which item of several "is called" a sample name—essentially a matching-to-sample situation. Thus, *the matching-to-sample procedure itself* may serve as a contextual cue for responding in terms of sameness

because of the formal properties of the training and testing situation in combination with the child's history with a variety of relational tasks such as naming. Note that we are not appealing to naming as a mediational process. From the point of view of relational frame theory, a history of relational responding would explain the derived relations seen both in naming and in equivalence. Such a history in one area may affect responding in another, however, through the development and instantiation of a common behavioral process.

To assess the kinds of contexts in which equivalence will emerge, more research should be done on the ease with which equivalence is shown in a variety of tasks and experimental preparations other than matching to sample, especially with very young children. Work needs to be done on ways of breaking up and preventing the formation of equivalence relations because this may assess whether there are contexts in which equivalence is unlikely. To assess the role of history in equivalence, longitudinal studies need to be conducted on the development of equivalence in infants younger than 2 years (because children already show equivalence by then; Devany, Hayes, & Nelson, 1986).

The experimental procedure used in many studies of equivalence could also have encouraged its formation. Some studies (e.g., Lazar, Davis-Lang, & Sanchez, 1984; R. Saunders, Wachter, & Spradlin, 1988; Sidman et al., 1985; Sidman & Tailby, 1982) exposed subjects to identity matching (though often in unreinforced trials) before beginning the training with the arbitrary stimuli. This may have cued the application of the relation of sameness in the arbitrary matching-to-sample task that followed, much as SAME did in the present studies. In other studies (Devany et al., 1986; Gatch & Osborne, 1989; Spradlin et al., 1973; Wetherby, Karlan, & Spradlin, 1983), subjects were instructed to choose the comparison that "went with" the sample, perhaps cuing a frame of coordination.

Rather than view such factors as problems to be avoided, the present concept suggests that they are important variables to be studied. Verbal humans appear to have a wide variety of relational responses under contextual control, and, in the present study, pretraining probably only actualized already learned behavior. If pretraining had been omitted and

the words "same," "different," and "opposite" were used as relational stimuli, the results could well have been similar. The study of contextual control (including verbal control) over relational responding may provide a fruitful avenue of research for the study of equivalence, exclusion, and other types of relations.

Increasingly, behavior analysts are viewing stimulus equivalence and similar phenomena as important preparations for the investigation of human language and cognition. The present study provides a method for the study of a much wider range of stimulus relations that can be brought to bear on arbitrary stimuli. As such, it may be useful for behavior-analytic investigations of complex cognitive and verbal phenomena.

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